Global Ocean Data Assimilation Experiment (GODAE) High Resolution Sea Surface Temperature Pilot Project (GHRSST-PP)

Strategy and Initial Implementation Plan

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Executive Summary

This document describes in detai l the strategy and implementation plan of the Global Data Assimilation Experiment (GODAE) high-resolution sea surface temperature pilot project (GHRSST-PP). **The aim of the GHRSST -PP is to coordinate a new generation of global, multi -sensor, high-resolution (4 km and 6 hours) , SST products for the benefit of the operational and scientific community and for those with a potential interest in the products of GODAE.** The GHRSST-PP is a direct response to the observations of the International GODAE Steering Team (IGST) that concluded: "for the goals of GODAE, a significant enhancement of the presently available Sea Surface Temperature (SST) data stream and products is required".

The GHRSST -PP has been established to give international focus and coordination to the development of a new generation of global, multi -sensor, high-resolution, SST products. At the end of the GHRSST -PP project preparation phase , it will enter into the project demonstrati on phase from 2002-2005. In this decade (2003-2013), enhanced ocean data sampling from satellites (e.g., ENVISAT, EOS, ADEOS, MSG) and in situ infrastructure (e.g., Argo and new operational ship of opportunity measurement campaigns) is expected. The GHRSS T-PP aims to capitalize on these activities and data streams to demonstrate the benefits and utility of integrated global ocean SST products. Ocean sampling of this nature is not guaranteed for the future and the onus is on the user community to demonstra te that the benefits are tangible, valuable, and worthy of sustained support (GODAE, 2000). The GHRSST-PP is committed to this goal.

Against this background, the aim of the GHRSST-PP is to:

- ***Ensure the provision of rapidly and regularly diffused, high -quality sea surface temperature products at a fine spatial and temporal resolution (4 km and 6 hours) that meet the diverse needs of GODAE, the scientific community, operational users and climate applications at a global scale.***

The most promising way to ach ieve the GHRSST -PP aim is to combine observations from complementary infrared (IR) and passive microwave (PM) satellite sensors on polar -orbiting and geostationary platforms together with quality controlled in situ observations from ships and buoys. The i mminent advent of AATSR, MODIS, GLI and SEVIRI, key infrared satellite sensors for improving SST data quality, as well as new satellite microwave radiometers such as TRMM TMI and AMSR, makes this an appropriate time to develop and demonstrate the benefits of such an approach. Each satellite sensor type has unique benefits but individual limitations. The ATSR and AATSR sensors have inherently higher accuracy than the AVHRR series and provide a robust measure of atmospheric attenuation, but lack the extensive coverage of the latter. MODIS and GLI provide wide swath coverage together with enhanced spectral capabilities over previous instruments. The GOES, GMS and new SEVIRI (MSG) imaging radiometers flown on geostationary satellites provide regular (1/2 hour) o bservations of a full earth disk but, alone, lack global coverage. Microwave radiometers operating in the 6 -10 GHz frequency band such as TRMM TMI and AMSR are insensitive to the presence of cloud but have coarser spatial resolution and reduced radiometri c fidelity when compared to IR sensors. In principle, the merging of these complementary measurements can deliver SST products with enhanced accuracy, spatial and temporal coverage.

In order to achieve the GHRSST-PP target, innovative but robust data merging strategies and methods have to be developed that optimise the resolution, coverage, accuracy and temporal characteristics of diverse input data. Five clear strategic objectives have been established:

1. Identify data providers (including measurements of SST from satellite and in situ sources and satellite data (e.g., brightness temperature) from which SST observations are derived) and data users across all application sectors and establish data a ccess agreements, timely data exchange routes, protocols and services.

2. Characterize the quality of existing satellite and in situ SST data sources through validation exercises and identify differences between them by inter   -comparison at local, regional and global spatial scales and for daily, weekly and monthly temporal scales.

3. Develop innovative data integration and assimilation methods that exploit existing SST datasets through data merging/fusion in order to generate improved multi   -sensor SST products.

4. Identify and promote the research and development needed to address outstanding issues concerning, for example, the access to and exchange of data, merging of complementary SST data streams, appropriate cloud clearing strategies and SST algorithms.

5. Implement GHRSST -PP methods as a demonstration system to provide timely SST products that are responsive to user requirements during the 2003   -2005 GODAE demonstration period.

The strategic objectives described above constitute the foundation of the GHRSST   -PP *thematic strategy* coordinated by the GHRSST-PP Science Team. There are four GHRSST -PP themes as follows:

- ❖ **Theme I:**   Specification and delivery mechanism of sea surface temperatur   e products required by different users and diverse.
- ❖ **Theme II:**   Characterisation and identification of differences between SST fields derived from existing satellite and in situ data sources.
- ❖ **Theme III:**   Targeted research and development for SST data integration.
- ❖ **Theme IV:**   Generation of improved, multi   -sensor, demonstration SST products through integration and assimilation.

Each theme is designed to guide the implementation of the GHRSST   -PP by achieving several practical objectives. The GHRSST-PP project will deliver a demonstration system that integrates data from existing international data sources using state -of-the-art communications and analysis tools. The output of this system is a set of new   generation merged SST demonstration data products suitable for use in GODAE and the scientific community as a whole.

Primary GHRSST-PP SST demonstration products of both surface skin SST and subsurface SST will be produced at the highest spatial and temporal resolutions possible (nominally every 6 hours). In all cases data products will provide global coverage and will be accurate to bett   er than 0.5 K. Furthermore, the SST fields will not be interpolated thereby preserving the integrity of the source data as much as possible. By defining 6 hourly products, users can easily differentiate between day and night time only conditions.

1. Concept for a GODAE High Resolution SST Pilot Project

1.1 Introduction and rationale

Sea Surface Temperature (SST) c ontains information about climate conditions that directly affect human health, economy, and enterprise (WCRP, 1995). SST is an ocean parameter that is widely used for describing ocean circulation and dynamics, in the study of upper -ocean physical and biogeochemical processes, as a boundary condition for meteorological models, as a central factor in studies of air sea fluxes, and as an indicator for climate change. The records of SST date back 100 years and accurate satellite infrared data have been acquired for the last 20 years (although the historical SST record and the modern SST record, primarily based on satellite observations, are fundamentally different). Operational systems are now in place to provide regular SST measurements at a global scale, and such datasets are available through the Internet. The development of computers, satellites, sensors, observational programs, SST data archives, faster and more efficient means of electronic communication, and supporti ng scientific research has further developed the skill and usefulness of SST observations. Consequently, it is widely assumed that the operational monitoring of SST provides accurate and dependable ocean measurements requiring lim ited further research. While it is true that SST data products at global and regional scales do have a considerable impact on modern operational oceanography and meteorology, *in practice the accuracy, sensitivity, and sampling resolution of the routinely recorded global SST products is far from optimal* . Users of global SST data sets increasingly demand higher fidelity in terms of accuracy and spatial and temporal resolution. If these demands are to be met significant changes in approach are necessary.

The Global Ocean Data Assimilation Experiment (GODAE) aims to establish a comprehensive, integrated observing system providing data that will be assimilated into state -of-the art models of the global ocean circulation in near rea l-time (GODAE, 2000). GODAE has identified a need for operational high-resolution SST products to properly constrain models of upper ocean circulation and thermal structure (e.g., Smith and Lefebvre, 1997; LeTraon et al. 1999). The International GODAE Steering Team (IGST) concluded that, for its goals, a significant enhancement of the presently available SST data stream and products is required. In particular:

❖ The temporal and spatial resolution of existing SST data sets do not fulfi l the requirements of GODAE and are not adequate for Numerical Weather Prediction (NWP), data assimilation and ocean forecasting purposes.

Similar conclusions were reached by the OOPC/AOPC workshop on Global sea surface temperature data sets (WMO, 1999):

❖ There is a broad range of SST product requirements including accuracy, spatial and temporal resolution that are not being satisfied despite the available data resources and scientific knowledge.

In response, the IGST convened a three-day workshop in November 2000 to discuss the prospects for a new generation of high resolution SST product s (Smith, 2001). At this workshop, an international panel of experts drawn from all fields of SST research and operations concluded that:

❖ It is appropriate to recognise that satellite and in situ SST are fundamentally different, that satellite SSTs (be they derived from infrared or microwave sensors) are vastly more numerous than any in situ SST measurements and that satellites offer the only way forward for a realistic global SST product.

❖ The most appropriate way to provide high accuracy SST data products at high -resolution in space and time is by merging complementary satellite and in situ data sets.

❖ Both 'skin' and subsurface SST f ields are required in both real -time and in delayed -mode and at a variety of temporal and spatial representations including raw, composited and gridded forms.

❖ Although the satellite datasets, the technical and scientific knowledge and, th e science and data management tools are already available separately, the formal combination of these resources in order to develop a new generation of global SST products is absent.

The GHRSST -PP has been established to give international fo cus and coordination to the development of a new generation of global, multi -sensor, high -resolution, SST products. In this decade (2003 -2013), enhanced ocean data sampling from satellites (e.g., ENVISAT, EOS, ADEOS, MSG) and in situ infrastructure (e.g., Argo and new operational ship of opportunity measurement campaigns) is expected. The GHRSST-PP aims to capitalize on these activities and data streams to demonstrate the benefits and utility of integrated global ocean SST products. Ocean sampling of thi s nature is not guaranteed for the future and the onus is on the user community to demonstrate that the benefits are tangible, valuable, and worthy of sustained support (GODAE, 2000). The GHRSST-PP is committed to this goal.

This document describes in detail, the strategy and Implementation plan of the GHRSST -PP. It provides a thorough description of project obje ctives, strategy, components, expected outcomes, implementation and final evaluation. It is based on the consensus opinions of the GHRSST -PP Science Team (Annex II) following prolonged discussions.

1.2 Objectives and scope for a GODAE high resolution SST pilot project (GHRSST-PP)

The target of the GHRSST-PP is to:

❖ **Ensure the provision of rapidly and regularly diffused, high-quality sea surface temperature products at a fine spatial and temporal resolution, that meet the diverse needs of GODAE, the scientific community, operational users and climate applications at a global scale.**

The most promising way to achieve the GHRSST-PP target is to combine observations from complementary infrared (IR) and passive microwave (PM) satellite sensors on polar-orbiting and geostationary platforms together with quality controlled in situ observations from ships and buoys. The imminent advent of AATSR, MODIS, GLI and SEVIRI, key infrared satellite sensors for improving SST data quality, as well as new satellite microwave radiometers such as TRMM TMI and AMSR, makes this an appropriate time to develop and demonstrate the benefits of such an approach. Each satellite sensor type has unique benefits but individual limitations. The ATSR and AATSR sensors have inherently higher accuracy than the AVHRR series and provide a robust measure of atmospheric attenuation, but lack the extensive coverage of the latter. MODIS and GLI provide wide swath coverage together with enhanced spectral capabilities over previous instruments. The GOES, GMS and new SEVIRI (MSG) imaging radiometers flown on geostationary satellites provide regular (1/2 hour) observations of a full earth disk but, alone, lack global coverage. Microwave radiometers operating in the 6-10 GHz frequency band such as TRMM TMI and AMSR are insensitive to the presence of cloud but have coarser spatial resolution and reduced radiometric fidelity when compared to IR sensors. *In principle, the merging of these complementary measurements can deliver SST products with enhanced accuracy, spatial and temporal coverage.* One approach relies on wide-swath high resolution IR data from polar orbiting sensors such as AVHRR, MODIS and GLI to provide a high-resolution base data set. Passive microwave (PM) data from TMI and AMSR could be used to overcome the worst problems of cloudy areas. Geostationary satellite data such as those from GOES, SEVIRI and GMS could be used to account for diurnal variability and, in situ data may constrain, test and check all of the satellite data. Other approaches employ the use of numerical and statistical modelling to provide combined sensor SST data sets that account for the cool skin of the ocean and thermal stratification (e.g., Kawamura, 2002) or utilize the unique measurements of the AATSR to provide a robust "calibration" data source for new "multi-sensor" SST algorithms.

The production of an accurate and consistent single stream SST data resource at high temporal and spatial resolution, based on the merging of complementary satellite data sets, offers considerable advantages including:

❖ High product accuracy,
❖ Timely data provision,
❖ Better availability and reliability of error statistics,
❖ Better spatial and temporal resolution,
❖ Enhanced long-term stability of input/output data,
❖ A high level of input/output data quality control,
❖ Limited duplication of effort by agencies and institutions,
❖ Focus of scientific and operational competence,
❖ Enhanced user confidence and,
❖ Ease of data provision.

Table 1.1 describes the major satellite instruments that have an SST observation capability relevant to the GHRSST-PP objectives. Not all of these instruments will be continued in their

present configurations (e.g., the next series of GOES satellites will provide a limited capability for SST retrieval) and launch dates may be delayed. Furthermore, not all data are currently available in the public domain requiring data access and use agreements to be formulated.

Sensor	Type	Satellite	Orbit	Date	Accuracy	Spatial Res	Swath
AVHRR/2	IR/VIS	NOAA/TIROS-N	NP	1978-2005	0.5 K	1.1 km	2600 km
MODIS	IR/VIS	EOS-TERRA/AQUA	NP	1999-2006	0.3 K	1.1 km	2330 km
ATSR series	IR/VIS	ERS	NP	1991-2002	<0.3 K	1.1 km	512 km
AATSR	IR/VIS	ENVISAT	NP	2002-	<0.3 K	1.1 km	512 km
GLI	IR/VIS	ADEOS-II	NP	2002-	< 0.5 K	1.0 km	1600 km
SEVIRI	IR/VIS	MSG	G	2002-	< 0.6 K	4.0 km	ED
GOES imager	IR/VIS	GOES	G	1995-	0.7 K	4.0 km	ED
VISSR	IR/VIS	GMS	G	1977-	< 0.5 K	5.0 km	ED
VISSR	IR/VIS	Meteosat	G	1981-2003	1.5 K	5.0 km	ED
TMI	PM	TRMM	LE	1997-	0.5 K	50 km	760 km
AMSR-E	PM	ADEOS-II	NP	2002-	$0.3^{\ddagger}$ K	50 km	1600 km
AMSR	PM	EOS-AQA	NP	2002-	$0.3^{\ddagger}$ K	50 km	1600 km
VIRS	IR/VIS	TRMM	LE	1997-	< 0.5 K	2 km	720 km
MSMR	PM	Oceansat-1	NP	1999	1.3 K	150 km	1400 km
HiRED	IR/VIS	MTSAT	G	2003	< 0.6 K	??	ED
AVHRR/3	IR/VIS	METOP	NP	2003-	< 0.5 K	1.1 km	2600 km
VIIRS	IR/VIS	NPP	NP	2005-2010	< 0.5 K	0.8 km	1700 km

Table 1.1 Summary of available satellite sensors providing SST measurements. (G=geostationary, NP=Near Polar, LE=Low Earth, ED=Earth Disk)

1.2.1 Definition of Sea Surface Temperature

The dynamic nature of the upper ~10m ocean thermal structure has significant implications for the validation, interpretation and, merging of complementary satellite SST data sets. It is important to recognise that individual SST data streams have inherent limitations and that there are significant differences between measurements of essentially the same param eter by different approaches. These are related to differences in instrument design, measurement technique and the variable nature of the surface ocean. In order to properly define GHRSST-PP demonstration data products, it is necessary to carefully consider the dynamic thermal structure of the upper ~10 m of the ocean surface. It is no longer appropriate to simply refer to "skin" SST and "bulk" SST in the traditional manner. More precision is needed in terminology if more accurate measurements of SST are to be optimally exploited. Accordingly, these issues demand careful attention in terms of GHRSST-PP demonstration data product conception, validation and interpretation.

SST is a complex parameter to define exactly (Barton, 2001; Taylor et al, 2001) because the upper ocean (~10 m) has a complex and variable vertical temperature structure that is related to ocean turbulence and the air-sea fluxes of heat, moisture and momentum (e.g., Wick et al, 1996). Definitions of SST provide a necessary theoretical framework that can be used to understand the information content and relationships between measurements of SST made by different instruments. The following statements attempt to provide this framework and encapsulate the effects of the dominant heat transport processes and time scale of variability associated with distinct vertical and volume regimes within a vertical element of the water column (horizontal and temporal variability is implicitly assumed):

❖ The interface SST, SST_{int}, is the temperature of an infinitely thin layer at the exact air-sea interface. It represents the temperature at the top of the SST_{skin} temperature gradient (layer) and cannot be measured using current technology. It is important to note that it is the SST_{int} that interacts with the atmosphere.

❖ The skin SST, SST_{skin}, is a temperature measured within a thin water layer (<500 micro meter) adjacent to the air-sea interface. It is where conductive, diffusive and molecular heat transfer processes dominate. A strong vertical temperature gradient is

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[‡] Estimate based on Wentz and Meissner (1999) model.
[‡] Estimate based on Wentz and Meissner (1999) model.

characteristically maintained in this thin layer sustained by the magnitude and direction of the ocean-atmosphere heat flux. Thus, SST_{skin} varies according to the actual measurement depth within the layer. This layer provides the conne ctivity between a turbulent ocean and a turbulent atmosphere.

❖ The sub-skin SST, $SST_{sub-skin}$, is representative of the SST at the bottom of the surface layer where the dominance of molecular and conductive processes gives way to turbulent heat transfer. It varies on a time scale of minutes and is influenced by solar warming in a manner strongly dependent on the turbulent energy density in the layer below.

❖ The near surf ace ocean temperature (~10 m) is significantly influenced by local solar heating and typically varies with depth over a time scale of hours. Consequently "SST" measurements should always be referenced against a specific depth or an average over a depth ra nge. We use the notation SST_{depth} to refer to any temperature within the water column beneath the $SST_{sub-skin}$ where turbulent heat transfer processes dominate. The traditional "bulk" SST is related to this measure. SST_{depth} should always be quoted at a specific depth in the water column; e.g., SST_{5m} refers to the SST at a depth of 5m.

While SST_{skin} may be approximated using measurements made by an infrared radiometer, measurements should specify the specific wavelength and viewing geometry of the instrument. These dictate the exact part (i.e., depth) of the SST_{skin} layer temperature gradient (which is itself variable) that is actually measured (McKeown et al. 1995). Consequently, SST_{skin} should always be quoted at a specific wavelength in the water column; e.g., $SST_{skin10.5\mu m}$ refers to the SST within th e skin layer measured at a wavelength of 10.5 µm. $SST_{sub-skin}$ may be approximated by measurements made by a low frequency (~6 -10 GHz) microwave radiometer as seawater emissivity is much lower in this region of the electromagnetic spectrum resulting in measu rements to depths of ~1 mm. SST_{depth} is measured using traditional temperature sensors mounted on buoys, profilers and ships at any depth and in this terminology is a refinement to the traditional term "bulk" SST which does not indicate a specific depth of measurement. SST_{skin} variability is generally de-coupled from the related SST_{depth} that is often used as a proxy for $SST_{sub-skin}$ (e.g., Fairall et al. 1996; Kent et al. 1996; Donlon and Robinson 1997; Minnett and Hanafin 1998; Donlon et al. 1999; Minnett and Ward 2000; Ward and Minnett 2001). In addition, significant decoupling occurs when diurnal stratification of the upper few meters of the sea surface prevails (e.g., Barton 2001). Diurnal temperature excursions of > 3 K are not unco mmon in the upper 5 m of the water column (Stramma et al, 1986; Yokoyama and Tanba, 1991).

Figure 1.1 illustrates schematically the relationships between SST_{int}, SST_{skin}, $SST_{sub-skin}$ and SST_{depth}. Figure 1.1(a) shows the characteristic thermal stru cture at night or during the day if moderate to strong winds homogenize the temperature in the upper water column below the skin layer. In this circumstance $SST_{sub-skin}$ is similar to SST_{depth} through the surface mixed layer but is characteristically warmer than the cooler SST_{skin}. Figure 1.1(b) depicts the characteristic situation for late morning -early afternoon following a period of insolation in conditions of light/absent wind. Thermal stratification of the upper ocean layers has occurred resulting in s ignificant temperature differences between SST_{int}, SST_{skin}, $SST_{sub-skin}$, and SST_{depth}. In reality a complex vertical profile is observed rather than the idealized situations described in Figure 1.1(a) because of small -scale interleaving and overturning pro cesses causing gradients in both horizontal and vertical directions (Ward and Minnett, 2001).
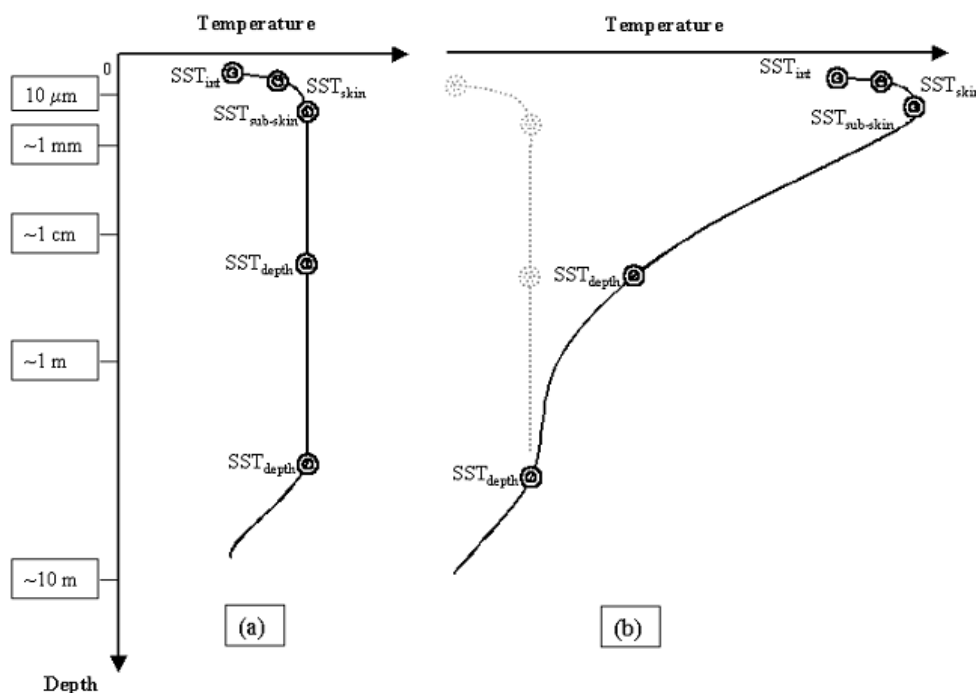
Figure 1.1 Idealized temperature profiles of the near surface layer (~10 m depth) of the ocean during (a) night time and daytime during strong wind conditions and (b) daytime low wind speed conditions and high insolation resulting thermal stratification of the surface layers.

It is clear that the determination of SST depends on the measurement technique, the depth and time of measurement, prevailing environmental conditions and, the sensor that is used. In summary, the characteristic profiles presented in Figure 1.1 highlight two fundamental properties of upper ocean (~0-10 m) SST:

1. SST_{int}, SST_{skin}, $SST_{sub-skin}$ and SST_{depth} are related but have quasi -independent spatial and temporal variability whose magnitude may differ considerably depending on the local history of ocean -atmosphere conditions. This underscores the motivation to refine the existing reference to "bulk" SST that is universally used in oceanography and meteorology to a more precise definition (SST_{depth}) that accommodates known functionality while at the same time permitting continuity of existing records.
2. Knowledge of the measurement technique, local time and, exact depth of measurement is fundamental when relating SST_{depth} measurements to SST_{skin}, $SST_{sub-skin}$ or other SST_{depth} measurements.

These properties are particularly important when considering half-hourly SST observations made by geostationary IR satellite sensors that have a range of local time across their swath. It follows that they are also important in the case of wide -swath polar orbiting sensors where additionally, orbit drift may cause slow changes in local overpass time.

1.2.2 Definition of GHRSST-PP SST products

The GHRSST -PP will provide a number of different data streams at a variety of spatial and temporal resolutions and different delivery constraints. All GHRSST-PP products should:

❖ Properly account for differences between conventional subsurface temperature measurements and measurements made using infra red radiometer instruments (the "skin effect"),
❖ Where possible, account for temporal variability of vertical ocean temperature structure due to diurnal stratification,

❖ Be available in both real -time and in delayed -mode for environmental and climate applications, in a variety of temporal and spatial representations including raw, composite and gridded forms and,

❖ Include proper estimates of uncertainties including analysis error and bias.

Delivery constraints

Although the inter-relationship between product resolution, accuracy and delivery time is complex, the timely distribution to users is an essential component of the GHRSST -PP. Two primary data streams can be defined that are constrained by delivery time:

❖ Real time[†] (RT) data streams.
❖ Off-line (OfL) data streams.

RT data stream products are expected to be slightly weaker demonstration data products because not all potentially contributing data may be available in RT and not all anc illary data used in quality assurance may be readily accessible. In contrast, OfL data stream products will have access to the full ensemble of ancillary data all owing a more rigorous quality control procedure, the use of fully optimised data merging strategies and, be subject to independent validation tests. OfL data stream products will provide GHRSST -PP demonstration data products that have the highest accuracy, spatial, and temporal resolutions possible and are targeted for use in climate research.

Two GHRSST product s can be readily defined adhering to the model shown in Figure 1.1 according to the wavelength of the radiation measured by satellite sensors :

❖ The majority of satellite sensors making SST measurements are infrared sensors operating in the 3.5-12μm spectral band that fundamentally provide SST_{skin} data.

❖ Passive microwave sensors provide a measure ment thought to closely approximate the $SST_{sub-skin}$.

User constraints

However, t he parameter desired by some users (e.g., for assimilation into coupled air   -sea and ocean models) is a measure of the near surface or mixed   -layer ocean temperature, traditionally taken from the "bulk" SST and here related to SST_{depth}. Unfortunately, there are no satellite sensors that are able to measure SST_{depth} and developing a consistent, accurate and reliable measurement of SST_{depth} based on satellite observations poses a challenge for the GHRSST-PP. In situ sensors including moored and drifting buoys, VOS observations and other ships of opportunity, are unable to sample the top ~1mm layer of the ocean   which gives rise to the   signal detected by satellite sensors. Furthermore, these data are isolated point measurements and lack complete coverage of the global ocean, although   they do provide the only description of the subsurface temperature structure that is required to relate satellite IR observations to the SST at depth.

Recent research (Donlon et al., 1999; Donlon et al., 2001) suggests that, above a wind speed of approximately 6 ms^{-1}, the relationship between the SST_{skin} and SST_{1-5m} is well characterised by a cool bias of -0.17 ±0.07 K rms. for both day and night time conditions   based on analysis of high quality in situ observations obtained for different oceans and seasons and using different state -of-the-art infrared radiometer systems.   This may provid e an alternative basis for the recovery of SST_{depth} temperature fields from SST_{skin} and or $SST_{sub-skin}$ observations in appropriate wind speed conditions.   Some groups (e.g., Kawamura 2002) use modelling techniques to account for the

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[†] Following the GODAE Strategic Plan (Smith and Lefebvre , 1997), we use a   definition of real -time that accommodates most users who require timely data, be that for operational windows (6   -12 hours) or for people monitori ng climate and environmental conditions (one to several days perhaps). The qualification "near" in this context has little meaning.

effects of thermal str atification and the cool skin of the ocean and thereby provide an estimate of the subsurface SST. This approach provides a more complete solution for the low wind speed regime with the additional benefit of novel data products describing thermal stratification.

Sensor spatial resolution constraints

The spatial resolution of GHRSST-PP demonstration data products is dictated primarily   by the spatial resolution offered by the various source satellite data streams and the vast volumes of data associated with high resolution multi -spectral data sets . Polar orbiting IR radiometer systems are able to provide very high -resolution data sets (typical cell dimension of ~1 km at nadir) and global data sets are now becoming routinely available (e.g.,   MODIS has global 1 km SST product). In addition, research satellite instruments such as ASTER provide extremely high-resolution thermal infrared data (0.09 km at nadir) for selective areas although global coverage is not available.   A nominal resolution cell of 4 km at nadir is operational ly generated by the NOAA AVHRR series of radiometer using the Global Area Coverage (GAC) sampling scheme. In addition the highest spatial resolution data available from geostationary sensors (e.g., GOES and MSG) will also be at 4 km. The ATSR series provides an operational SST $_{skin}$ data set at a resolution of 10 arc minutes (~18km at the equator) . Note that   all of these resolutions are significantly reduced   further from nadir point within the swath of   each sensor. In contrast, polar orbiting microwave radiometer systems offer w ide-swath coverage but at a reduced spatial   resolution of ~50 km.   By over sampling the signal from these sensors, they are able to provide gridded SST measurements at a sampling interval of 25 km.   Collectively, these data are expected to constitute the GHRSST -PP "base" data set.

Sensor temporal resolution constraints

Temporal resolution and coverage are dictated primarily by the constraints imposed by individual satellite orbit configuratio ns and swath width. Geostationary IR sensors are, in some cases, capable of providing half-hourly observations of a full earth disk whereas wide-swath polar orbiting sensors may p rovide a local measurement twice per day in most areas (in some cases, gaps remain in the tropical regions)   collectively providing daily global coverage. Coverage provided by infrared instruments is also limited by cloud cover, which limits the spatial sampling of polar orbiting systems and the temporal sampling of geostationary systems.   As the highest frequency of measurement is constrained by data derived from geostationary sensors, the maximum practical temporal resolution possible will be limited to a near global coverage every half-hour.

User requirements

The technical constraints described above need to be matched against the requirements for high resolution SST data sets.   In general, f or operational applications, timeliness of data is critical and several modelling groups (e.g., GODAE, UK Met. Office)   have indicated a preference for   daily, high-resolution SST products. Delivery delays of more than one day render data meaningless as the next-day product supersedes the previous day products. Some operational users prefer all data (including individual satellite passes)   as soon as they are a   vailable so that they can be used immediately within operational analysis . Some groups indicated that they would prefer unmerged data fields while others   prefer night -time only data   (merged or unmerged)   , to avoid the complicating effect of diurnal variability. It is clear that no single GHRSST-PP product specification will meet all of these requirements.

Scientific and regional requirements requir   e both higher temporal and spatial resolution data products. In particular, t he spatial resolution of numeric al ocean forecasting models is steadily becoming finer and finer   . For example,   the European DIADEM   project (See http://www.theyr.is/diadem/project/) will use model grids as small as 2 km. At present such fine grids are used operationally only to generate the statistics of ocean variability but if they are to be used to represent and forecast the actual variability of currents at these short length scales, the use of observed SST to initialise and validate such predictions becomes an important   issue. Addressing temporal resolution, r ecent work in the Arabian Sea (R. Evans, Work in   progress)

demonstrates that the time scale of SST variability is much shorter than previously expected having 1K temperature changes within < 6 hours based on an the analysis of a 6 hourly time series of MODIS and AVHRR/Pathfinder data . This suggests that m odels into which GHRSST -PP SST products are assimilated must contain appropriate physics and forcing to permit a proper model response. T able 1.2 describes seve ral example SST observational requirements in terms of grid size, delivery constraints and accuracy.

Purpose	Grid	Delivery	Accuracy (K)	Reference
NWP	50-100 km	12-24 hrs	0.2-0.5	GOOS
Regional NWP	20-50 km	6 hours	0.2-0.3	GOOS
ENSO	30-100 km	5 day	0.2-0.3	WCRP (1998)
Coastal oceanography	<10 km	3 hours	0.2	
Mesoscale oceanography	10-50 km	3 hours	0.2	
Tropical air-sea fluxes	2° x 2°	Daily	0.3 K	WCRP/SCOR(2000)
Climate studies (CLIVAR)	200-500km	Monthly	0.1 K	WCRP(1998)
Climate studies (WOCE)	5° x 5°	Monthly	0.25-0.5	Weller and Taylor (1993)
	5° x 5°	Monthly	0.1 K	OOSDP (1995)
	2° x 2°	Monthly	0.1 K	OOSDP (1995)

Table 1.2 Typical SST observational requirements. Note that a relative accuracy of 0.1 K is possible for many sensor specific data providing information on structural patterns that may be assimilated into models.

General GHRSST-PP demonstration product specification

The GHRSST -PP workshop specified a requirement for global, cl oud-free SST fields having high temporal (daily or better) and spatial (at least 10 km) resolution and accuracy better than 0.5 K (Smith, 2001). SST_{skin} products will be derived from infrared satellite data sets and $SST_{sub-skin}$ data products from PM satellite data sets . The exact definition for an SST_{depth} product is difficult due to the complex nature of the upper ocean layers and in particular, the potential for strong diurnal variability. In many cases, users requiring an SST_{depth} measurement are interested in the SST that is not influenced by rapid diurnal variability and the simplest method to provide these data products is to either use night-time only observations (although at the cost of temporal resolution) or to use data only in high wind speed conditions . Day time data may be screened for stratification when wind speed conditions are > 6 ms^{-1}. A more rigorous approach relies on the use of models to explicitly account for cool skin and warm stratification effects (e.g., Kawamur a, 2002). A nominal depth of 1 m has been chosen for the GHRSST -PP SST_{depth} products which is beneath the effect the most intense diurnal variability (e.g., Stramma et al, 1986; Yokoyama and Tanba, 1991).

Table 1.3 summarises primary GHR SST-PP SST products that will all be produced at the highest spatial and temporal resolutions possible (nominally every 6 hours).

GHRSST-PP RT demonstration products		GHRSST-PP OfL demonstration products	
GHRSST-PP ID	Description	GHRSST-PP ID	Description
RT_SSTS_4K RT_SSTS_4KE	**SST_{skin}**: 6 hourly @ 4 km grid + error statistics	OFL_SSTS_4K OFL_SSTS_4KE	**SST_{skin}**: 6 hourly @ 4 km grid + error statistics
RT_SSTSS_4K RT_SSTSS_4KE	**$SST_{sub-skin}$**: 6 hourly @ 4 km grid + error statistics	OFL_SSTSS_4K OFL_SSTSS_4KE	**$SST_{sub-skin}$**: 6 hourly @ 4 km grid + error statistics
RT_SSTD_4K RT_SSTD_4KE	**SST_{1m}**: 12[†] hourly @ 4 km grid + error statistics	OFL_SSTD_4K OFL_SSTD_4KE	**SST_{1m}**: 12[‡] hourly 4 km grid + error statistics

Table 1.3 Definition of GHRSST-PP SST demonstration products.

[†] A 12 hourly field is assumed here due to the reduced number of contributing observations as a consequence of using the 6 ms^{-1} wind speed constraint.

[‡] A 12 hourly field is assumed here due to the reduced number of contributing observations as a consequence of using the 6 ms^{-1} wind speed constraint.

In all cases these data aim to have global coverage accurate to 0.5 K or better. The SST fields should be uninterpolated and may have missing data, a format that is preferre   d for assimilation purposes. This also preserves the integrity of the source data as much as possible. In addition, the individual satellite passes derived from each sensor that are used in the data merging procedure should also be available (although no t considered "products" of the GHRSST -PP). By defining 6 hourly products, users can easily differentiate between day and night time only conditions.

As almost all applications require an estimate of product errors (uncertainties), these will accompany each GHRSST-PP demonstration data product as a separate ancillary product derived from a compilation of on-going product validation efforts. Error statistics will be based on statistical analysis of all available contemporaneous satellite and in situ   data at DDS sites to provide a quantitive estimate of data   accuracy (normally expressed as an rms. Deviation).   In addition , product confidence flags for each pixel will provide   information relating to the actual derivation of the final SST value. The aim of these data is to provide information that can be used to assess the uncertainties in the final SST values . Table 1.4 describes a preliminary set of confidence data that will evolve and   be refined according to the   evolving analysis methodology adopted by the GHRSST-PP.

Example GHRSST-PP SST confidence data
Data source (including wavelengths) used in SST   (e.g., AVHRR LAC /GAC, ATSR, MODIS, SEVIRI, AMSR, TMI etc)
Cloud flagging tests used (e.g., Dynamic threshold, gradient operator, texture operator, spatial c oherence, version number, etc.)
Number of pixels used for average from each data source
SST Algorithm and version used
Merging algorithm and version used
Fill value for absent data (if used: this could be part of a data product header)
Time of data acquisition for each data source used
Ice detected in pixel (Confidence in ice edge position and detection)
Land in pixel
Centre latitude
Centre longitude
Aerosol detected in pixel
Overall confidence value in % for this pixel (based on an aggregate score)

Table 1.4 Description of example GHRSST-PP primary SST product confidence data.

For users requiring different spatial and temporal   resolution data sets, conventional sub-sampling tools may be used to generate " secondary" GHRSST-PP products based on further composite or subsets of the primary data sets described in Table 1.4   although this does not form a part of the GHRSST-PP.

1.2.3 A need for operational high quality in situ observations.

In order to merge complementary SST data sets it is first necessary to have a quantitive description of all source data and a full understanding of the actual content of   these data. The quality and credibility of any satellite derived SST product depends on comprehensively accounting for the uncertainties associated with a specific instrument and the technique it employs to determine SST throughout the satellite mission l ifetime. Accurate and dependable pre - and post launch sensor calibration together with a reliable and well characterised measurement concept underpin the integrity of further geophysical data abstractions. Product validation actually quantifies how succe ssfully a satellite derived SST data product represents the true SST defining the measured signal. It addresses fundamental issues such as the physical processes characterising the satellite measured radiance, the long term performance of the satellite instrument, any time -space inconsistencies within a satellite -in situ database used to perform the

validation exercise, and the stability of the derived SST products with time.   Sensor calibration is therefore distinct from data product validation and a   succ essful satellite SST data product is characterised as one derived from a satellite instrument having   verified accurate and reliable pre - and post -launch sensor calibration supported by a comprehensive long term in situ validation programme.

A comprehensi ve satellite SST validation strategy is   therefore required within the GHRSST -PP. The objective of this activity is to obtain a contemporaneous, long term, cost effective suite of SST observations from a wide variety of in situ and satellite instrumentatio n for a range of atmosphere and ocean conditions. These data are necessary to provide a description of the ocean-atmosphere conditions prevalent at the time of satellite SST measurement which, when used in synergy, will quantify the accuracy of a particula r satellite SST data product. Table 1.5 describes major in situ SST data sets that are relevant to the GHRSST-PP.

Name	Type	Location	Date	Accuracy (K)
TAO/TRITON	Moored buoy array	Tropical Pacific	1987 -	±0.1
PRIATA	Moored buoy array	Tropical Atlantic	1997 -	±0.1
NDBC	C-MAN moored stations	Coastal USA/UK	1981 -	±0.1
Japanese Meteorological Agency	Moored buoy	Coastal Japan	1992 -	±0.1
Argo	Profiling drifting buoy	Global	2003 -	±0.05
Global drifter program	Drifting buoy	Global	1979 -	±0.1
Explorer of the Seas	Ship of opportunity (Skin SST)	Caribbean	2000 -	±0.05
R/V Mirai	Ship of opportunity (Skin SST)	Trop. Pacific	2002-	±0.1
M/V Val de Loire	Ship of opportunity (Skin SST)	Celtic Sea/Bay of Biscay/E Channel	2002-	±0.1
VOS	Volunteer observing ships	Global	1853 -	±0.1 - ±1.0
SISTeR	Research SOO (Skin SST)	Global regions	1996-	±0.05
CIRIMS	Ship of Opportunity (Skin SST)	TBD	2001-	±0.1
DAR011	Research SOO (Skin SST)	Australian waters	1999-	±0.1

Table 1.5 Summary of currently available in situ infrastructure providing SST measurements suitable for the GHRSST-PP.

When validating satellite SST data sets having accuracies better than 0.3 K (e.g., ATSR, AATSR, MODIS) as well as understanding the local temporal and spatial variability of the measur ed SST field, the quality of in situ measurement becomes a critical factor. Unless a comprehensive suite of accurate and reliable ocean and atmosphere measurements accompany in situ SST validation data, a full understanding of the satellite derived SST me   asurements will remain limited. In particular, the continued use of SST_{depth} measurements to validate SST_{skin} satellite products must be replaced with operational in situ SST_{skin} validation programmes.   Ideally, a source of in situ SST_{skin} observations mat ching the present spatial and temporal coverage provided by drifting and moored buoys is required to address this issue. The recent   developments in using ship of opportunity (SOO) high quality in situ radiometer systems highlighted in Table 1.5 demonstrate that this process is now underway and wider plans for operational deployments are in preparation (e.g., Donlon et al, 200 2). However, these efforts should be coordinated in terms of instrument calibration, measurement technique and   measurement specificat ion (including spectral intervals and temporal averaging) through existing mechanisms such as the recent infra red radiometer inter-comparison workshop held in Miami (Minnett, 2001).

1.3 General strategy

The success of the GHRSST -PP depends on providin g a number of well -defined and robust SST data products that should be made available in a timely fashion. In order to achieve such a goal, innovative but robust data merging strategies and methods have to be developed to optimise the resolution, coverage, accuracy and temporal characteristics of input data. These have to be

carefully balanced not only against limitations of data availability and throughput, but also against available human and computer resources.

The GHRSST -PP provides a unique international framework in which scientists, users and agencies already engaged in activities working with satellite and in situ SST data are encouraged to participate in the specification, generation and distribution of specific GHRSST -PP SST products. The success of the GHRSST-PP depends on providing well-defined and robust products that will be made available in a timely fashion. One approach relies on wide -swath high resolution IR data from polar orbiting sensors such as AVHRR, MODIS and GLI to provide a high -resolution base data set. Passive microwave (PM) data from TMI and AMSR could be used to overcome the worst problems of cloudy areas. Geostationary satellite data such as those from GOES, SEVIRI and GMS could be used to account for diurnal variability and, i n situ data may constrain, test and check all of the satellite data. Other approaches employ the use of numerical and statistical modeling to provide combined sensor SST data sets that account for the cool skin of the ocean and thermal stratification (e.g ., Kawamura, 2002) or utilize the unique measurements of the AATSR to provide a robust "calibration" data source for new "multi-sensor" SST algorithms.

In order to achieve the GHRSST -PP target, innovative but robust data merging strategies and methods h ave to be developed that optimize the resolution, coverage, accuracy and temporal characteristics of diverse input data. Five clear strategic objectives have been established:

1. Identify data providers (including measurements of SST from satellite and in si tu sources and satellite data (e.g., brightness temperature) from which SST observations are derived) and data users across all application sectors and establish data access agreements, timely data exchange routes, protocols and services.

2. Characterize the quality of existing satellite and in situ SST data sources through validation exercises and identify differences between them by inter-comparison at local, regional and global spatial scales and for daily, weekly and monthly temporal scales.

3. Develop innovative data integration and assimilation methods that exploit existing SST datasets through data merging/fusion in order to generate improved multi -sensor SST products.

4. Identify and promote the research and development needed to address outstanding issues concerning, for example, the access to and exchange of data, merging of complementary SST data streams, appropriate cloud clearing strategies and SST algorithms.

5. Implement GHRSST -PP methods as a demonstration system to provide timely SST products that a re responsive to user requirements during the 2003 -2005 GODAE demonstration period.

Five interconnected project components are indicated in Figure 1.2 which provides a schematic representation of the GHRSST -PP project. It illustrates the concept of a system that integrates data from existing internationa l data sources using state -of-the-art communications and analysis tools and generates new merged SST products described in Table 1. 3. The GHRSST -PP components are:

❖ A dyn amic distributed database (**DDD**) based on a virtual database system that will coordinate access and exchange of existing international satellite and in situ SST data (e.g., held by international GDAC, DAAC and SAF) each with a characteristic spatial resolution, sampling frequency and accuracy, for use within the GHRSST-PP. The DDD will also coordinate access and dissemination of all GHRSST-PP products.

- ❖ Software tools that access and merge internationally distributed SST datasets in order to create the RT and OfL GHRSST-PP products described in Table 1.3. This is referred to as satellite data integration (**SDI**). This implies the use of several standard data formats (e.g., HDF, netCDF, BUFR) and routines being made available to translate between them.
- ❖ A user support facility (**UIS**) co-ordinates and manages all interactions with the GHRSST - PP user community including general information, project contacts, data access, product descriptions, metadata repository, master index of GHRSST -PP datasets and, all user feedback.
- ❖ A quality analysis facility that includes a set of activities that test, inter -compare and validate input SST data streams considered by the GH RSST-PP at local, regional and global time-scales and at a variety of spatial resolutions. At its core is the concept of a diagnostic data set (**DDS**). The DDS will contain high -resolution satellite data contemporaneous with other satellite data and where p ossible, in situ observations for globally distributed "DDS-sites" that adequately represent all global climatic regimes. The DDS provides a means to validate GHRSST-PP products.
- ❖ Input from new and existing international SST research and development (**R&D**) activities form an essential input to all GHRSST -PP activities and will be fostered within the GHRSST-PP as a distinct activity.

Figure 1.2 highlights the fact that a fundamental part of the GHRSST -PP is concerned with the effective management and coor dination of large distributed data sets, in near real time. This can only be realised through effectively coordinated international cooperation. This GHRSST -PP strategy is considered in more detail in section 2 of this document.
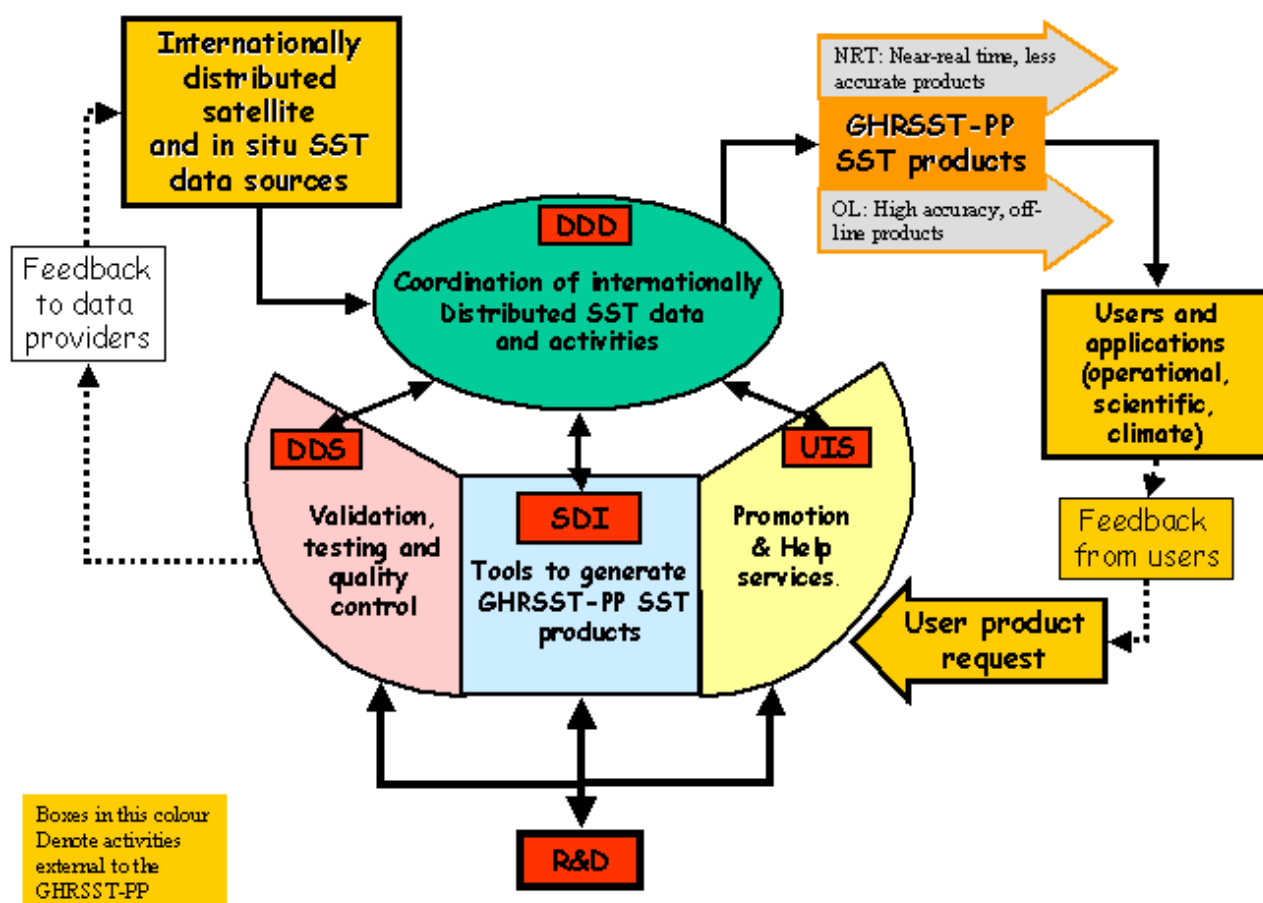

Figure 1.2 Schematic diagram showing the fundamental components of the GHRSST-PP showing inter-relationships and feedback loops.

Two feedback loops are shown: the first feedback loop provides results and recommendations to SST data providers based on the GHRSST activities that will lead to improvements in specific SST data streams through independent validation, testing and comparison of existing data sets. The second fee dback loop ensures that users are fully integrated into the GHRSST -PP project by providing, through the U IS, a method to receive user requirements, recommendations and suggestions.

1.4 Context of the GHRSST-PP within GODAE and general guiding principles

The GHRSST -PP is an initiative initiated by the GODAE project in accordance with its overall strategy of using pilot projects to develop GODAE infrastructure and in particular, the GODAE "Common". The Common consists of the infrastructure (such as data and product servers), the data products and data streams develop specifically for GODAE, assimilation products from existing national research and operational activities and the scientific knowledge of the GODAE partners. While participants in GODAE are seen as prime user s, the GHRSST -PP intends to provide demonstration data products and services in near real time to a wider scientific, operational and industrial community. The GHRSST-PP is expected to benefit from and significantly contribute to the GODAE common data products and data servers.

The following guiding principles describe the general GHRSST-PP strategy:

❖ The success or impact of the GHRSST -PP is a measure of how well the project is able to provide SST demonstration data products that are accurate, relevant, quality controlled and accessible in a timely fashion given a specific user request (particularly those of GODAE groups),
❖ The GHRSST -PP will encourage the unhindered flow of data resources and information both within and between different international activities,
❖ Appropriate technologies will be used within the GHRSST -PP that are clearly capable of evolution to accommodate the dynamic nature of Internet -based data transport syst ems, software applications, the Internet infrastructure, and, disparate data formats,
❖ The GHRSST -PP will build on existing networks and associated platform independent software interfaces (e.g., the distributed ocean data system, DODS), databases, agencies, data and metadata repositories by strengthening collaborations, network development and partnerships and, only where necessary, establishing new databases, linkages and collaborations,
❖ The GHRSST-PP is not the owner of dat a or data streams: it co -ordinates the collection, exchange, integration, quality control, dissemination and access to existing data,
❖ The value, accuracy and quality of all data within the GHRSST -PP will be enhanced through innovative synergy,
❖ The GHRSST-PP will uphold data licensing terms and conditions and respect the rights of data owners (either as individuals or as projects) in terms of data access, publication and use restrictions,
❖ Data, tools, methods and techniques used within the GHRSST -PP should be current, reliable and of sufficient quality to be used with confidence,
❖ Adoption of appropriate, practical and cost -effective, standards -based data management and interoperability protocols, analysis, archive methods and tools will be encouraged at all levels.

1.5 Users, benefits and outcomes

GODAE has a fundamental dependence on SST data and products and, in addition, the value -adding activities of GODAE also require improved SST products, particularly in terms of resolution (e.g., coastal forecasting) . But there are many other international activities (e.g., NWP, research programs CLIVAR, GEWEX, WOCE and climate monitoring) that require a new generation of SST

product. The GHRSS T-PP user community is expected to be diverse in terms of product application and requirements but drawn mainly from:

> ❖ Numerical weather prediction,
> ❖ Global/regional Ocean applications (GODAE stream),
> ❖ Climate and long-term monitoring,
> ❖ Oceanographic and meteorological research and technology,
> ❖ Coastal, local and regional industrial activities.

There are also significant scientific benefits expected from the GHRSST-PP which include:

❖ Understanding and overcoming systematic differences between in situ, satellite PM and IR SST products through inter-comparison and validation,

❖ Development of consensus opinions on cross - and inter -calibration of PM and IR satellite sensors including support to scientific and technical activities relating to algorithms, vicarious calibration and other sensor-related technology development efforts,

❖ Diurnal stratification and the thermal skin temperature deviation will be included for the first time in consistent global SST products,

❖ A well specified global SST_{depth} product will be made available,

❖ Recommendation of SST data binning algorithms and merging strategies;

❖ Establishment of a scientific framework for creating a multi -sensor SST ti me series derived from the synergistic merger of PM and IR data streams.

Systematic measurements of the ocean SST will reveal previously unknown patterns and physical mechanisms of oceanic variability, leading to better understanding, modelling and predic tion of ocean variability in the future. The GHRSST-PP builds on the application of results from past basic research and current operational capability ultimately leading to enhanced operational capability. It is clear that without basic research today, there will be limited operational successes and economic gains in the future.

There are significant economic and technological benefits to the GHRSST -PP project that are founded in this diversity of users and applications and their common nee d for high resolution SST data products. ***The GHRSST -PP will coordinate a critical mass of scientists, operational agencies and users that will take responsibility to demonstrate that the highest quality SST data sets can be generated, in an operationally sustainable and efficient manner.*** It will provide a co -ordination focus for the synchronisation of assimilation and integration procedures, validation techniques, algorithms and data formats associated with the operational use and development of a long term, multi -sensor satellite SST data set. The GHRSST -PP is expected to make a significant contribution to international Earth observation innovation, policy, decision - making and strategy formulation. Further more, the e fficient and cost -effective supply of SST products to users is inherent in the GHRSST -PP. The approach of a distributed database (DDD) provides hitherto unprecedented flexibility without the need for large data archiving overheads.

2. GHRSST-PP thematic strategy.

The success of the GHRSST -PP requires the finest scientific and technical knowledge brought together through careful coordination, planning and innovative science data handling methods. The GHRSST-PP itself does not have the direct funding to develop and implement   all aspects of the project, but instead provides focus and coordination for nationally funded activities working with SST data at all levels .   The implementation of the GHRSST   -PP depends on the successful coordination of an international consortium   of funded activities   that collectively implement the project, including its final transition into a fully operational demonstration system.

The strategic objectives described in §1.3 constitute the foundation of the GHRSST -PP **thematic strategy** coordinated by the GHRSST-PP Science Team. There are four GHRSST-PP themes as follows:

> ❖ **Theme I:**   Specification and delivery mechanism of   sea surface temperature products required by different users and diverse applications.
> ❖ **Theme II:**   Characterisation and identification of differences between   SST fi elds derived from existing satellite and in situ data sources.
> ❖ **Theme III:**   Targeted research and development for SST data integration (SDI).
> ❖ **Theme IV:**   Generation of improved, multi-sensor, SST products through integration and assimilation.

Each theme is designed to guide the implementation of the GHRSST   -PP by achievi ng several practical objectives.   Due to the scientific and technical complexities and the detailed inter   - relationships between activities within each theme, thematic activities may be further subdivided into modules. In this way, the GHRSST-PP provides stimulation and coordination for all activities in progress, proposals for new activities and, strategic vision for future activities in order to achieve the project objectives. Some module activities already exist   within international (e.g., the DODS network, NASDA new generation SST, Argo) or national programmes (e.g., MERCATOR project, real-time SST for meteorological forecasting, SOO SST validation activities), be part of the GODAE Common or, may be recommendations for new initiatives considered necessary to fulfil the project thematic objectives and reach the GHRSST   -PP target. This type of project structure provides considerable flexibility, facilitates project organisation and allows a scaleable approach to tackling problems as they arise.

2.1 GHRSST-PP organisation structure

The GHRSST -PP organisation structure is composed of two main components ov   erseen by the IGST: a project Science Team (ST) and   f our thematic coordinators, cooperating in a continuous but flexible interaction. Communication and information flow within the GHRSST   -PP will be achieved using:

> ❖ Periodic meetings (electronic and   physical as required) of the ST to review the project status,
> ❖ Meetings of ad -hoc thematic workgroups, related to specific thematic and/or modular activities,
> ❖ Use of automated computer messaging services (e-mail, mailing lists)
> ❖ Development and use of the UIS for discussion and documentation sharing.

Figure 2.1 .1 describes schematically the organisation structure of the GHRSST   -PP. The me coordinators are responsible for the coordination of modular acti   vities within each theme and provide the formal interface between GHRSST -PP activities and the ST. The chair of the ST acts as a formal interface to the International GODAE Steering Team (IGST) reporting all project activities directly or through the ST.
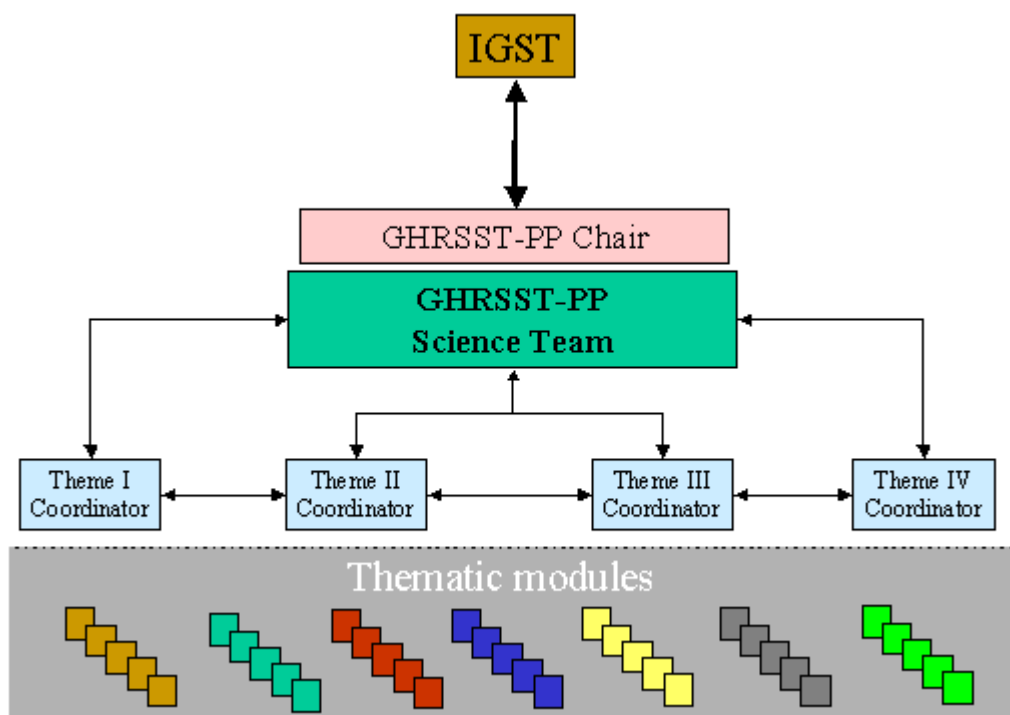
Figure 2.1.1 Schematic diagram of the organisation entities within the GHRSST-PP.

In addition to the development of the GHRSST -PP strategy and implementation plan (this document), the following Terms of Reference have been agreed for the GHRSST-PP ST:

(i)   Provide scientific guidance to, and as appropriate receive advice from, the International GODAE Steering Team on the scientific and technical issues associated with the implementation of the Project and on the use of products by GODAE.

(ii)   Develop an international consortium to undertake the implementation of the Project, including its final transition into an operational demonstration system.

(iii)   Provide advice and guidance on scientific and technical innovations relevant to the Project.

(iv)   Liaise as appropriate with other groups associated with the global ocean observing system, including the SST Working Group and Surface Flux Project (SURFA) of the Ocean Observations Panel for Climate.

(v)   Provide regular reports on progress to the International GODAE Steering Team.

The following sections describe in detail the theme based work plan for the GHRSST -PP. They provide a description of the thematic rationale, the practical objectives and recommended modular activities together with expected outcomes that are considered necessary to implement the GHRSST-PP.

2.2 Theme I: Specification and delivery mechanism of sea surface temperature products required by different users and diverse application.

The aim of this theme is to achieve GHRSST -PP strategic objective 1. Established applications of SST maps include their use in NWP, input to model data assimilation schemes, boundary condition specification and validation of global models, by ocean fishing fleets for locating fronts and different water masses, air -sea interaction, s hip routing, to provide environmental information required for naval surveillance, by environmental monitoring agencies monitoring water quality, for defining the climatic state of the ocean and as an indicator of global change.

Although satellite data pr ovide a global, spatially detailed view of SST that cannot be achieved by any other means, a growing community of users requires improved quality products.   For some operational users near real -time availability and frequency of observations are equally im portant. In some cases published SSTs have missing data replaced by climatological values, resulting in a product unsuitable for many applications. For monitoring climate variations, the absolute accuracy of SST measurement is paramount, but existing individual SST datasets are no better than ±0.5 K, and in the worst cases, bias may be significantly greater than this.   However, validation of AVHRR Pathfinder SSTs (Kilpatrick et al., 2001) in mid and low latitudes using radiometric SST $_{skin}$ measurements, show residual uncertainties of ±0.3 K (Kearns et al., 2000).

Considerable co-ordination will be required in tandem with innovative technology and foresight to facilitate the effective transfer of large data sets between international data users and provi   ders. Several systems are already pioneering the DDD approach (e.g., the Distributed Oceanographic Data System, DODS) and these require evaluation and testing for the purpose of the GHRSST-PP.

Given an evolving SST user community within a broad a   pplication sector, the following practical objectives are identified:

    1.1   Define the scope and extent of the user community   for GHRSST-PP SST products and ensure that GHRSST -PP demonstration data products meet the needs of the diverse SST user community.

    1.2   Develop a user information system (UIS) to promote all aspects of the GHRSST -PP and receive user feedback.

    1.3   To liase with data providers and agree access to data required by the GHRSST-PP.

    1.4   Establish an international virtual distributed dynamic database (DDD) approach to regional and global data   holdings (both real -time and delayed mode) building on existing international activities.

2.2.1 Theme I modules

Module I-i The GHRSST-PP User Information Service (UIS)

The purpose of this   module is to   create and sustain an active network for co   -operation and strategic planning which promotes interaction between those who use sa   tellite derived SST data for operational and climatic applications, and those involved in the production of such datasets.
This will be achieved by creating a User Information Service (UIS) interactive website.   The UIS website will be equipped with softwa re to permit the creation of an interactive web forum providing efficient communications and exchanges between the members of the network. Members will be able to post documents (through a moderator) which may range from an expression of their expert knowledge for dissemination to the network   or proposals intended to provoke discussion, to requests for information or the identification of problems. The posted documents   will be archived in a database, which can be searched by keywords, topic, author, date of posting etc.
Table 2.1.1 suggests several initial areas of discussion that will be promoted by the UIS system.

Specification of new SST products	New methods for better SST products
Recent trends in operational ocean modelling. Initialising and assimilating SST in ocean models. Validating models with measured SST. Role of SST in climate monitoring. Use of SST in climate modelling. Sensitivity of global warming detection to SST measurement error. Sensitivity of ocean-atmosphere fluxes to SST. The GODAE requirements. Requirement for error statistics and timeliness of data Do climate and operational SST requirements differ?	Early results from AMSR and AMSU. Results of work merging IR and PM data. Potential for using SEVIRI on MSG Electronic science techniques for blending widely distributed datasets. The use of dynamic distributed databases (DDDs) Application of DODS to satellite SST recovery. Networks of in situ SST measurement. Assuring security of ice edge detection/flagging in SST data.
State-of-the-art for satellite SST	**Towards operational implementation**
Measurement of SST by infra-red techniques. The thermal skin of the ocean. Diurnal warming. Cloud detection for IR sensors. ATSR: is a dual-view essential? A critique of existing global composite SST datasets. A potential role for geostationary IR sensors. Microwave radiometry in 2002/5.	The role of operational data providers. Can a DDD approach simplify the operational tasks? Who are the "owners" of operational oceanography? The importance of international collaboration. International projects and initiatives.
How to achieve the new SST products	**The benefits of improved SST products**
Scope for improvements in polar IR radiometry. Potential benefits of merging AVHRR and ATSR. Overcoming problems of stratospheric aerosol. Cloud detection. Ice/ice edge detection and flagging. Fusion of geostationary and polar orbiting data. Fusion of microwave and IR SST measurements. Skin or sub-skin SST, or both? Assuring accuracy with in situ measurements. Use of buoy networks. Use of ship-board radiometry.	Sensitivity of operational ocean model forecast accuracy to the quality of assimilated SST data. Dependence of climate models on SST quality. Sensitivity of air-sea exchange processes to accuracy of SST.

Table 2.1.1 Example GHRSST-PP UIS discussion topics.

An active discussion forum is urgently required within the GHRSST-PP between the SST measurement community, ocean modellers and climate scientists using SST. By bringing together different groups, the UIS will promote a more creative development of the new ideas emerging for achieving high-quality, high-resolution global SST datasets. It is clear that to effectively assimilate fine resolution SST data will require a close dialogue between the data producers and the modellers, which does not yet exist. Theme I will coordinate and structure such interactions.

For example, it is important that the remote sensing community be made aware of the challenge of measurements at finer resolution which are likely to be demanded by modellers in the near future. There is a surprising ignorance amongst some users of SST about the sampling limitations and accuracy constraints of the various techniques for measuring SST. Most significant of all is a continued failure by many users to appreciate the fundamental difference between the skin and subsurface (bulk) definitions of SST. At the same time, many of the experts in SST measurement, focussed on the detailed design of sensors, atmospheric correction algorithms and the ocean surface thermal microstructure, tend to lack a full appreciation of how the SST datasets they produce are used in practice for assimilation into operational models or for monitoring climate change. By exposing these groups to one another it is intended that their perspectives should be broadened and it is expected that progress will be made in resolving some of the outstanding SST measurement problems. In isolation, the SST data producer seeks to generate a product with a given sampling frequency and may use interpolation to cope with cloud cover. However, the modeller who assimilates those data may be able to cope with the data gaps caused by cloud and

might prefer the added complexity of doing so to the reduction in accuracy introduced by interpolation. These are the type of issues   that can best be resolved through the two   -way communication fostered by Module I-i.

The UIS pages will be open to anyone in order to publicise the GHRSST-PP and promote the uses of satellite derived SST data to   the wider operational and scientific communities. These will also serve to inform the wider science community about the GHRSST   -PP and as a means of recruitment of new members to the GHRSST -PP network. The web pages will provide a point of reference for all information on the GHRSST-PP.

Module I-ii GHRSST-PP Distributed dynamic database (DDD) system

The type of system proposed by GHRSST-PP to handle the input of a variety of satellite SST data products is to use a dynamic distributed database (DDD). This uses electronic techniques to treat archived SST products and other supporting data (e.g., in situ and other satellite data such as wind speed estimates) residing on remote servers as if they were local.   The use of a virtual database "populated" almost entirely with existing SST and related datasets, promises to be flexible and cost effective. This will require n egotiation of conditions to access datasets used by the DDD system including data-producing agencies, such as   NOAA, EUMETSAT and its SAF's, NASDA , ESA, CNES, NAVOCEAN, the DAAC's, national weather bureaux, or private companies such as Remote Sensing Systems that supply satellite products. It also requires the configuration of a suitable data exchange protocol.

One of the GHRSST -PP measure s of succ ess concerns the effective delivery of   GHRSST-PP demonstration data, products and information. In this sense minimalist data   exchange protocols based on standard network tools such as the ftp protocol are adequate in cases when data is to be "pushed" to users (rather than users "pulling" data from outside which is consid ered a less robust operational system). Pushed data feeds should provide data at regular intervals corresponding to the regular 6 hourly merged analyses SST products but also, when requeste d, individual satellite passes should be made available as soon as possible. This is because certain analysis schemes (e.g., UK Met. Office) are able to treat separate satellite SST data sources differently. In addition, GHRSST-PP products should be made a vailable in widely used operational data formats such as BUFR or GRIB   (WMO, 1994)   thereby facilitating their assimilation into existing operational assimilation schemes.

However, there is also a need for flexibility in terms of data exchange within the GH RSST-PP itself where relatively small amounts of scientific data sets (e.g., the DDS data) need to be exchanged on an hourly basis.   Often, collaboration between groups of researchers are frustrated by   the technical difficulties of sharing datasets. Different groups use different data formats and analysis packages, and cannot easily combine their data.   Network communications problems impede the collaborative efforts of geographically scattered groups   but more importantly,   centralized data repositories provide a poor solution to the support of   dynamically changing datasets such a s that envisaged in the GHRSST-PP DDS.

The Distributed Oceanographic Data system (DODS) is a framework for scientific data networking that simplifies all aspects of remote data access   . It is widely implemented and well supported, providing access to a c   onsiderable data resource.   The design of DODS   was based on two considerations:

❖ data are often most appropriately distributed by the individual or group that has developed them and,
❖ users generally prefer to access data from a familiar application software package.

DODS uses existing network protocols to allow direct access to any compatible datasets that activities care to make available. It uses existing, well understood technologies (based on the http

protocol) to transfer data via the Internet seamlessly providing users access to data in a variety of different formats. Furthermore, it can translate between data formats thus providing a framework for a highly distributed system that allows users to control the distribution of their own data and the way they access data from remote sites. Local data can be made accessible to remote locations regardless of local storage format by using local DODS servers. US GODAE already host DODS servers on the Monterey site and partner servers including PODAAC, Navoceano, IPRC and NASA/JPL (JPL currently serves the Pathfinder SST data sets via DODS), NASA/GSFC, NCAR, NOAA, US-GLOBEC also use the DODS system . As an example, DODS currently serves 6144x6144 (16 bit) SST images stored in HDF format . A "chunking" sy stem facilitates data transfer: the image is broken up into 512x512 compressed chunks (the size used here is defi ned by the data provider). A remote DODS request (via http) pull s the image chunks of interest, decompress them, reassemble them, and then pulls out a requested area from the image . This is very fast for small images. The entire SST image or a sub-sampled field may also be requested and the transfer time required is similar to that required to decompress the entire image.

The DODS system , together with ftp, provides an el egant and extremely flexible solution for the GHRSST-PP DDD system requiring minimal investment (it is freely available) in terms of configuration and operation while maximising data access within the GHRSST-PP. DODS servers installed at GHRSST-PP data provider sites can be accessed by users using one of several DODS clients (inclu ding IDL, Matlab, and standard web -browsers). A master ind ex of all GHRSST -PP data should be created and maintained at several different sites using a GHRSST-PP metadata repository which can be accessed via the UIS.

2.3 Theme II: Characterisation and identification of differences between existing satellite and in situ SST data sources

The aim of this theme is to achieve GHRSS T-PP strategic objective 2. Before merged multi -sensor data products can be generated, validation and inter-comparison of existing data streams is necessary to identify, characterise and provide solutions tha t account for systematic differences between data streams. In this way, the activities of Theme II directly interface to the activities of Theme III and IV . This will be achieved by creating and maintaining a time series of co-located satellite and in situ data at a nu mber of globally distributed "sites" (e.g., 2 ° x 2 ° areas) that collectively constitute a diagnostic data set (DDS). The location of preliminary DDS sites is shown in Figure 2.3.1 which include the TAO/TRITON array, the PIRATA ar ray and the DDS s ites proposed by the SIMBIOS project (Campbell, 2001).

The following practical objectives for Theme II have been identified:

3.1.   Negotiate access to satellite and in situ datasets used as input to the GHRSST-PP,
3.2.   Develop methodology and a collaboration framework for ongoing testing, inter-comparison and validation of complementary SST products,
3.3.   Create a diagnostic data set for a number of globally distributed sites,
3.4.   Create a framework for the regular inter -comparison of regional and global data streams and data sets.
3.5.   Populate the DDS database.

The DDS will provide a data set that is suitable for testing and developing appropriate data merging/fusion algorithms. A wide variety of globally distributed in situ SST measurements are available fo r validation and quality control activities that can be used for this purpose and access and availability to all these data need will be coordinated through the activities of Theme I.
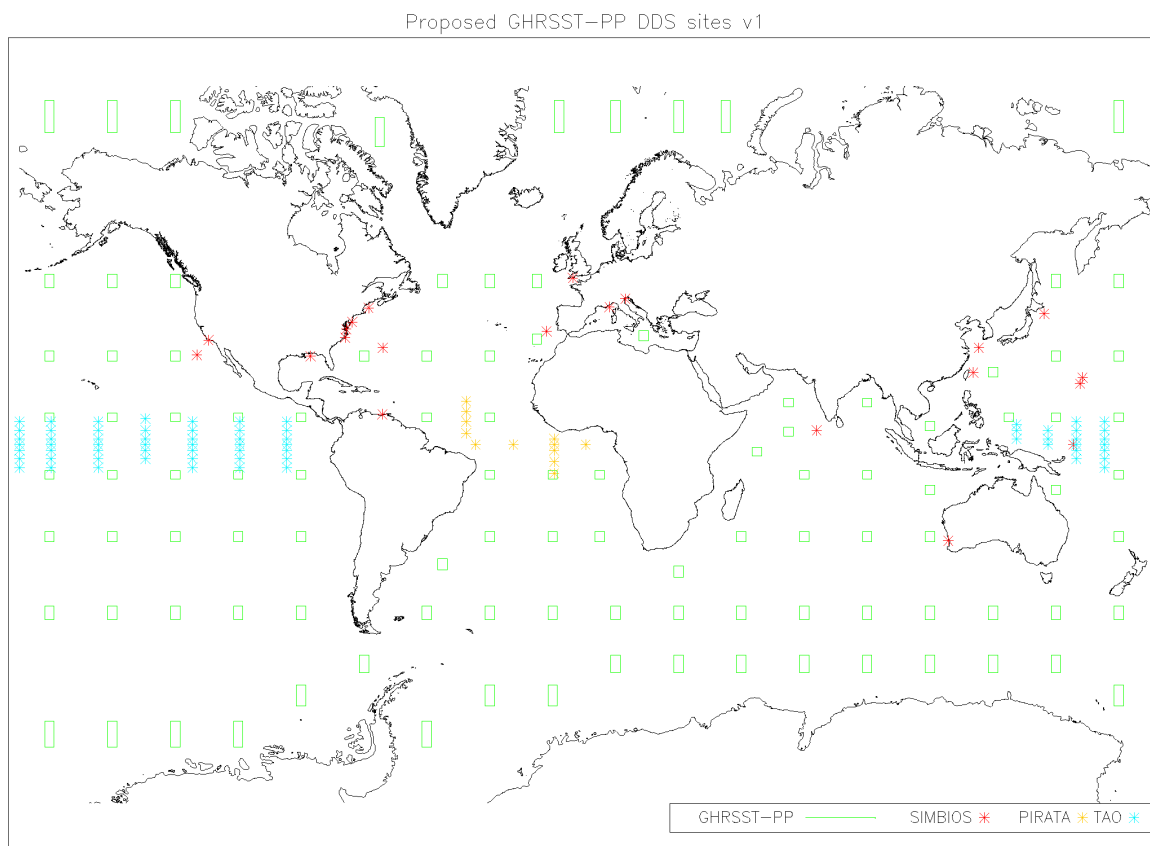
Figure 2.3.1 Geographical position of version 1.0 GHRSST-PP DDS high-resolution (green squares) DDS areas, the TAO/TRITON array, the PIRATA array and the DDS sites proposed by the SIMBIOS project.

The DDS will comprise of the following separate but linked entities: a suite of data and database access and manipulation to ols, a relational metadata database (RDB) and a WWW interface (hosted by the UIS). A database system will index high resolution, regional and global data sets that will be archived within the DDS system (also hosted by the UIS). Figure 2.3.2 schematically describes the general structure and activities of Theme II.

2.3.1 Theme II modules

The modules within theme II can be defined according to the spatial and temporal scale of inter - comparison activities required. Three related modules are identified that co nsider data inter - comparison at pixel, regional and global resolution scales. In the first case, inter -comparisons will be made using data at daily or even hourly resolution while the latter will consider composite data sets at weekly, monthly and annual resolutions. Consequently, the data requirements and necessary infrastructure for these activities are different (including data archive and exchange requirements).

Module II-i: Creation of DDS infrastructure

The primary activity focuses on the development of a diagnostic data set for satellite SST sensors assembled as a resource for validation of satellite data streams, evaluating and developing bias correction strategies and for understanding differences between complementary data. The DDS will serve as a repository for match -up in situ and small area satellite data products that are regularly used in a variety of scientific analyses in support of GHRSST-PP workshops, data merger studies, and time series studies. A precedent for this approach is provided b y the AVHRR Pathfinder Matchup Data base (Kilpatrick et al, 2001). It is expected that the DDS will provide a suitable resource for many of the activities within Theme III and IV. Careful quality control of all data is required (Emery et al. 2001; Kilpatri ck et al, 2001) if the DDS concept is to be successful

and, in order to maintain data quality, relevant documentation and calibration files associated with all data will be stored within the DDS system. It is foreseen that the main data transport route to the DDS will be via the DDD mechanisms via DODS interface.
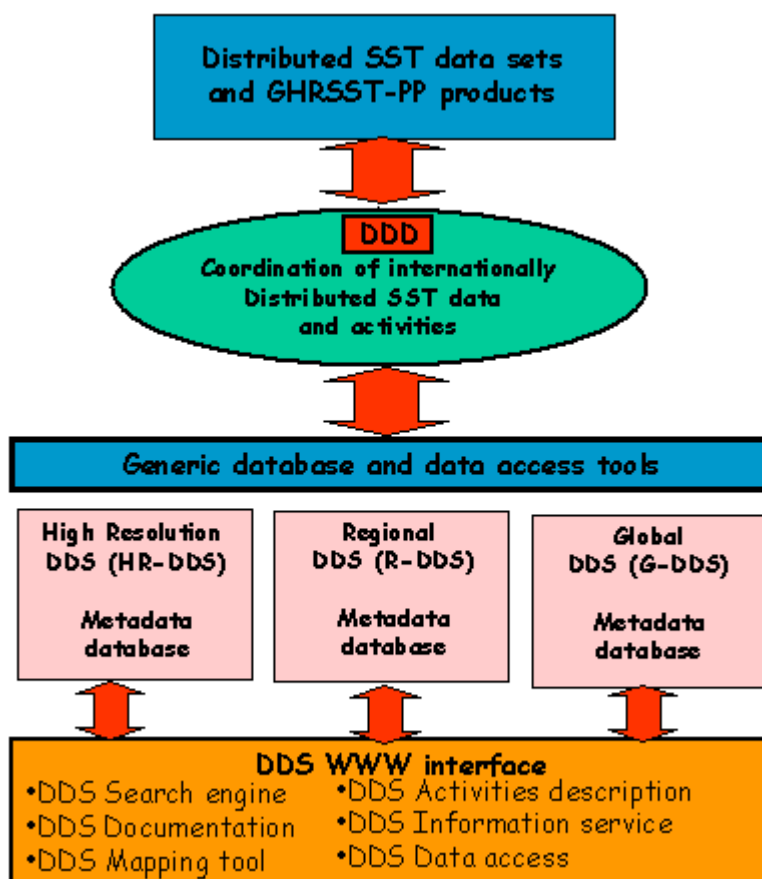
Figure 2.3.2 Schematic diagram describing the general structure of the GHRSST-PP DDS system.

The metadata data model indexing DDS data sets (locally or distributed) will be conformant with the DODS system and in addit ion, ISO-19115 geo -spatial metadata standard (ISO, 2001) and Dublin Core metadata initiative (DCMI, 1999) to facilitate usage and to assure international interoperability. The RDB will be accessed using a WWW interface hosted on the UIS that implements a dedicated search engine and tools enabling use rs to rapidly obtain information and data. In particular the GHRSST -PP DDS should take full advantage of interactive WWW based mapping technologies to provide tools that will enable satellite and in situ data to be mapped to a common map base. The following services are foreseen:

- ❖ General DDS search capability: A tool for users to query all holdings of the DDS,
- ❖ DDS system documentation and help facility,
- ❖ DDS data access service: A tool that allows new data to be submitted to the DDS,
- ❖ Interactive mapping tool: A tool for users to interactively map, combine and overlay image and in situ DDS data,
- ❖ Information service: A service for users who wish to be notified of new and updated data maintained within the DDS,
- ❖ Activity descriptions: Descriptions and information describing current DDS activities including how to contribute to a specific activity.

Module II-ii: Generation and composition of a high-resolution Diagnostic Data Set (HR-DDS)

The HR-DDS will comprise of a globally distributed 2 ° latitude × 2° longitude areas (or 'sites') for which all relevant data will be archived. Relevant data include measurements of satellite brightness temperatures together with in situ oceanographic and atmospheric data (e.g. radiometric SST, subsurface SST and salinity at various depths, wind speed and direction, humidity, air temperature, solar radiation etc. , including the height at which the measurements were taken) collected by a number of different instrument packages (e.g. profilers, buoys, above-water measurement devices) on a variety of different platforms including platforms, ships, moorings, and drifters. There are four major components involved in compiling the HR-DDS (see Evans, 1999):

❖ Obtaining and reformatting of in situ data.
❖ Extraction of the satellite data for each DDS.
❖ Match up of the satellite and in situ data.
❖ Quality control of satellite and in situ data.

The GHRSST-PP HR-DDS will benefit considerably by cultivating strong links to existing satellite sensor calibration and validation activities (e.g., SIMBIOS, NASDA, NASA, ESA) and other satellite and in situ match-up data base activities (e.g., MODIS, AVHRR Pathfinder). In particular, all GHRSST-PP DDS activities will be coordinated with the CEOS working group on satellite calibration and validation activates and results presented to the CEOS group at regular intervals.

Three types of HR-DDS site are foreseen following the definitions adopted by the SIMBIOS working group on merger activities (Campbell, 2001):

❖ **Category 1** sites that provide a comprehensive suite of in situ observations that could be used for vicarious calibration of satellite sensors and are likely to constitute only a small fraction of the DDS (e.g., regular SOO transects, IMET buoys, SURFA sites, platform observations).
❖ **Category 2** sites that provide satellite and when available, in situ data, as a time series that are likely to constitute the main component of the DDS.
❖ **Category 3** sites that consider any other contemporaneous data on an ad hoc basis (e.g., scientific cruise data sets).

Table 2.3.1 describes initial SST HR-DDS sites recommended by the GHRSST-PP which are plotted in the map shown in Figure 2.3.2.

Priority	Name	Location	Latitude	Longitude	Contact	Status	Comments
2	TAO moorings	Tropical Pacific	8°N - 8°S	137°E – 95°W	TAO office	Active	Mooring
2	PIRATA moorings	Tropical Atlantic	15°N – 10°S	38°W –0°	PIRATA office	In discussion	Mooring
2	SIMBIOS DDS sites	Global	Various	Various	SIMBIOS	Active	Agreed
1	Explorer of the seas SOO	Caribbean	18°N - 26°N	64°W - 80°W	U. Miami, RSMAS	Active	Regular SOO cruise line
1	Val DeLoire SOO	Celtic Sea, E. Channel & bay of Biscay	52°N – 43°N	2°W – 8°W	U. Southampton	2002-	Regular SOO cruise line
1	CIRIMS	TBD	TBD	TBD	APL, U. Washington	2002-	Regular SOO cruise line
2	GHRSST-PP DDS sites	Global	Global	Global	JRC, Italy	2001-	Multi Satellite time series

Table 2.3.1 Initial sea surface temperature high resolution Diagnostic Data Sites recommended by the GHRSST-PP.

Ideally, the HR-DDS should contain sufficient information to process satellite data from level L1 B through to L2 (see Table 2.3.2) although it is recognised that this is extremely demanding and probably beyond the scope of the GHRSST-PP. However, the HR-DDS provides a mechanism to entrain Level 0 and/or additional data if required. In addition to directly related S ST parameters, microwave satellite data will also be archived to assess the surface wind speed and total water vapour content that provide important additional information describing the atmosphere and ocean conditions at the time of measurement.

Level	Description
Level 0	Unprocessed instrument and payload data at full resolution.
Level 1A	Reconstructed unprocessed instrument data at full resolution, time referenced, and annotated with ancillary information, including radiometric and geometric calibrat ion coefficients and geo-referencing parameters, computed and appended, but not applied, to the Level 0 data.
Level 1B	Level 1A data that have been processed to sensor units.
Level 2	Geophysical variables derived from Level 1 source data at the same resolution and location as the Level data.
Level 3	Level 2 variables mapped on uniform space-time grid scales.
Level 4	Results from analyses of lower level data (e.g., variables derived from multiple measurements).

Table 2.3.2 Satellite Data Processing Levels

As currently envisioned, the HR-DDS would be generated routinely at the time L1 data are initially generated by space agencies and data providers. The emphasis is to facilitate generation of DDS data as much as possible. New data will be received in NRT (via the DDD) and automatically archived locally on a regular basis following a basic quality control check. Where possible, DDS data generation should be synchronised with sensor re -processing programmes to ease the burden of data ret rieval (e.g., ATSR) . A HR-DDS metadata record will be generated locally and submitted to the HR-DDS system via the WWW interface (as an e-mail for example) for ingestion into the HR-DDS metadata repository.

The HR-DDS is expected to serve data to the activities of Theme III and IV within the GHRSST-PP. In this context, four major outputs are expected from module II-ii:

- ❖ Real-time and delayed mode statistics on matches between sa tellite data streams, and in situ data,
- ❖ Confidence limits for all SST data sets,
- ❖ A manageable "global" resource for theme III and theme IV activities,
- ❖ Improvements in algorithms for retrieval of SST estimates (either skin or sub-skin),
- ❖ Improved validation and/or calibration of the remote sensing data stream,
  An enhanced reference data set containing highly detailed data relevant to scientific and technical development.

Module II-iii: Regional resolution diagnostic data set (R-DDS)

The activities within this module are concerned with compariso n of daily and temporal -composite L2 and L3 data sets of moderate spatial resolution for a number of globally distributed regional areas. This is an activity that is directly relevant to those providing resources, having a focus towards existing regional interests and associated expertise and thus, enhances the value and quality of all data streams. Regional data sets generated routinely by these existing activities will form the core data sets of this module although it may be necessary to constr uct dedicated data sets as required. Weekly, monthly and annual composite data will constitute the main data used within this module. This is a complementary approach to the highly detailed (although limited in number) HR-DDS concept and precludes routine inter-comparison and evaluation at the level of pixels, mainly because of the cost and volume of data. However, statistical inter -comparison of data streams on the scale of regions provides a very robust measure for the effectiveness of the various data merging, processing and analysis approaches that will be pioneered by the GHRSST-PP. The most critical operations for the development of multi-sensor satellite SST data sets are the data merging techniques employed and the flagging of cloud in satellit e IR measurements (both

further developed in Theme IV): diagnostics from these processes are not always retained and have only rarely been exchanged among centers.   Analysis of the R -DDS holdings will provide a solution to this situation through   inter-comparisons and monitoring of data streams   . Region-to-region inter -comparisons (at the overlaps) will provide an important means for calibrating and standardizing the data merging tools and methods being used.

Table 2.3.3 describes the sea surface temperature R -DDS areas recommended by the GHRSST - PP.

Name	Latitude	Longitude	Comments
NE. Atlantic	40°N - 60°N	20°W - 40°W	
Indian Ocean	20°S - 5°N	60°E - 90°E	
Kuroshio	30°N - 50°N	145°E - 170°E	
Mediterranean	32°N - 44°N	5°W - 36°E	Mediterranean basin
Southern Ocean	60°S - 40°S	60°W - 340°E	Large area
Gulf of Mexico	18°N - 30°N	98°W - 81°W	
Tropical Pacific	10°N -10°S	150°E – 80°W	Includes TAO moorings
Arctic ice edge	Various	Various	Follows ice edge
Antarctic ice edge	Various	Various	Follows Ice edge
Gulf Stream	25°N - 45°N	80°W - 55°W	
Central North Pacific	10°N - 50°N	160°E - 130°W	
Agulhas S Africa	40°S - 30°S	10°W - 30°W	

Table 2.3.3 Sea surface temperature R-DDS recommended by the GHRSST-PP.

Module II-iv: Global resolution diagnostic data set (G-DDS)

This module considers SST data at the global scale and   involves evaluation and testing of global data streams and data sets. Although global, coarse   resolution (0.25-10° spatial) scale L2 and L3 data composites will limit the level of data detail, inter -comparison activities will be similar to those described in module II -iii with an increased focus on the climate qualities of the data and thus   , require the use of   in situ subsurface temperature measurements.   At this level, it will also be possible to inter -compare SST products with other GOOS data and products (e.g., from   *Argo* or altimetry). It is also anticipated that information fed back   from users (e.g., SST analyses assimilated into GODAE models) will assume a higher profile in these comparisons . Feedback to this activity will be critical for all other activities. Issues of data delivery and timeliness are important within the G-DDS, as they will certainly affect the level of refinement that will be possible. It is also expected that Pathfinder-like activities would form an important element of this activity.

2.4 Theme III: Targeted research and development for SST data integration (SDI)

By its nature, this theme is fully coupled with each of the other themes   as indicated in Figure 1.2. In particular, the required research activities will be highly dependent upon   national projects and the DDS. The results of the target   ed research will be directly applied to the core GHRSST   -PP activities contained within theme III. Figure 1   .2 clearly shows a link between SDI and on   -going research and development to ensure that SDI is linked to new scientific innovations, tools, techniques and methods.

Not all aspects of merging complementary SST data sets are currently resolved to the stage where they can be relied upon to provide a robust solution   s. For example, parameterisation of the subsurface-skin SST difference and thermal stratif   ication at low wind speeds are particularly important. This theme is dedicated to coordinating existing research activities, and where appropriate, promoting new initiatives to provide solutions to outstanding scientific and technical issues within the GH RSST-PP. The aim of the theme is to ensure that scientific knowledge and procedures required to integrate the diverse data sets and produce the SST products are available for application within the other themes.

The practical objectives for theme IV depe   nd on those discussed in theme II and III with the following additions:

   3.1   Refine and develop methodologies and algorithms for merging SST products from all available data sources capitalising on synergy benefits   (especia lly for cloud flagging and calibration),
   3.2   Provide innovative tools (collectively called SST data integration (SDI)) that can produce merged SST products,
   3.3   Create a n international network to coordinate relevant R&D activities within the GHRSST-PP.

Several possible methodologies exist fo r the successful merging of complementary satellite data sets in the context of objective 3.1. One example is the New Generation SST data products   that are being developed in preparation of the ADEOS -II era which provide an estimate of a daily standard SS T measurement . Figure 2.4.1 schematically   shows the   evolution of thermal stratification over a 24 hour period highlighting the daily minimum   SST and a da ily mean SST together with typical satellite overpass times . The New Generation SST method aims to pro vide a measure of the daily mean SST by accounting for the amplitude fluctuation due to diurnal variability and the cool skin effect.
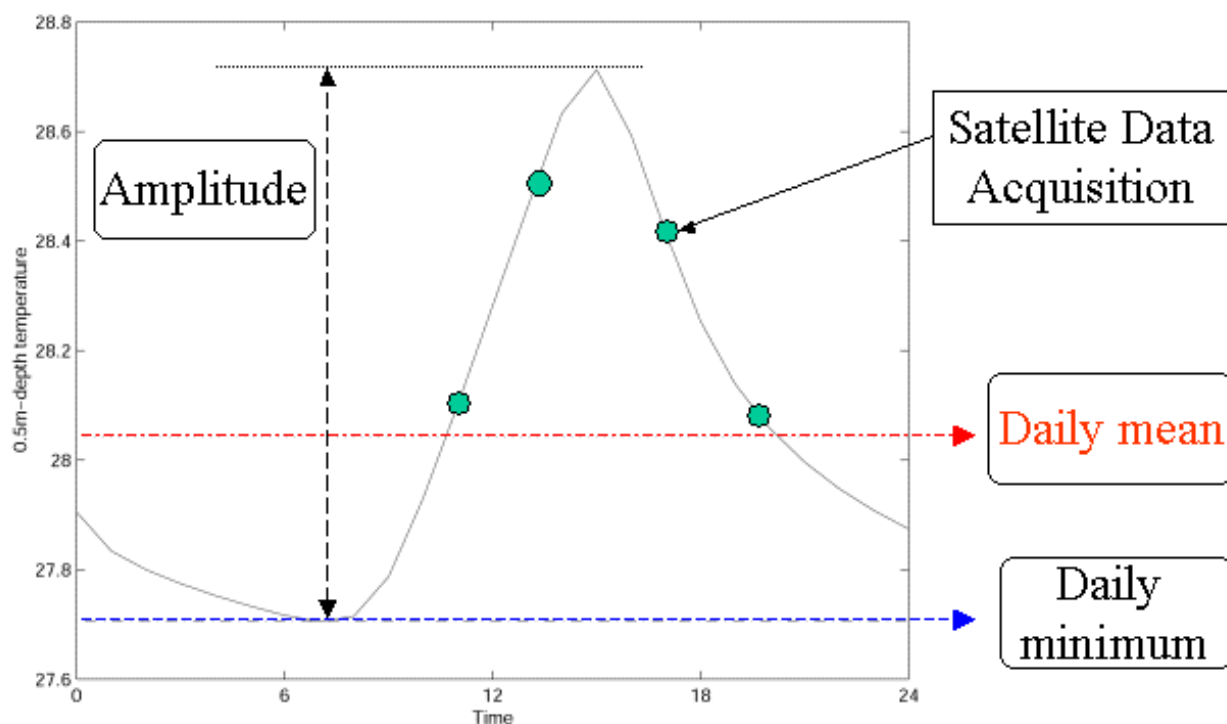
Figure 2.4.1 Schematic diagram showing the typical evolution of thermal stratification throughout a 24 hour period (Kawamura, 2002)

Figure 2.4. 2 schematically describes the   methodology used to provide SST $_{1m}$ or SST $_{skin}$ data products at a high temporal resolution using satellite   and in situ data. A combination of satellite and in situ data are used to derive a diurnal va   riation correction based on a one -dimensional surface-layer model having a grid interval of 0.25 m over a 3m depth (Kawai and Kawamura, 2000). This process provides a statistical estimate of diurnal variability that is then used in a regression procedure to obtain a daily standard SST. Statistical adjustment as a function of both wind speed and peak solar radiation as shown in Figure 2.4.3 are applied to high resolution (1   -4

km) Infrared data from the AVHRR, VISSR and VIRS to are then merged together wit h microwave SST observations to provide a merged SST_{1m} or SST_{skin} data product.
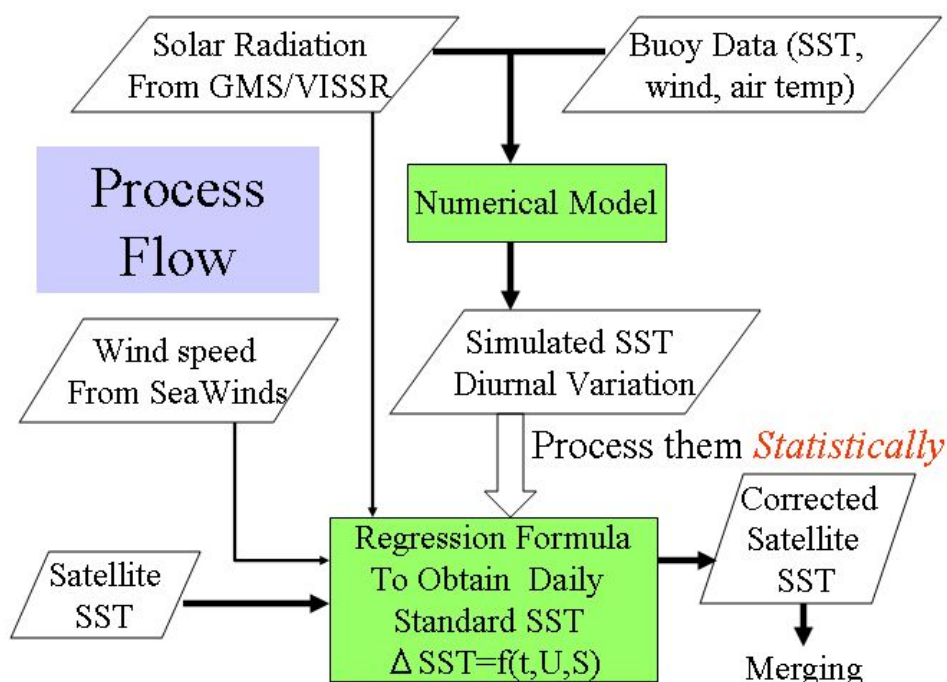
Figure 2.4.2 Schematic process flow diagram describing the methodology used to produce Merged SST_{1m} data products (Kawamura, 2002).
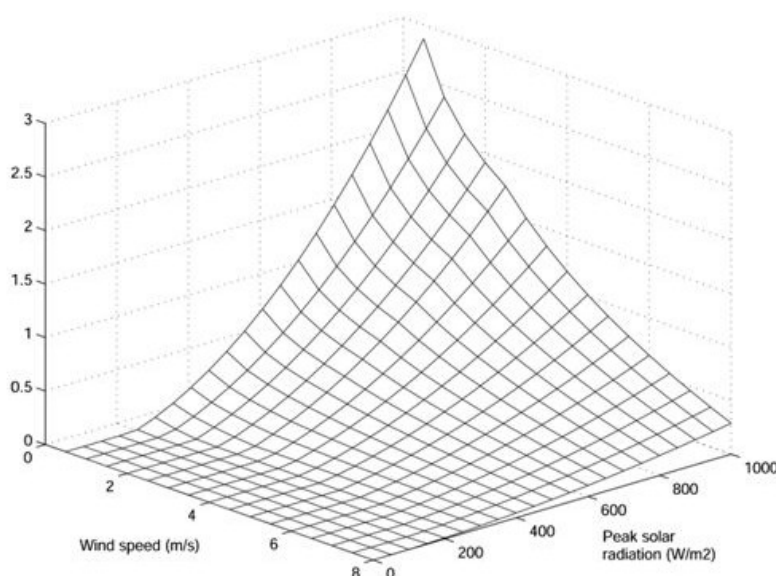
Figure 2.4.3 Function form of SST_{1m} regression equation (Kawamura, 2002).

2.4.1 Theme III modules

While much of the technical and scientific knowledge necessary to   realise the demonstration SST products such as the example given above, several areas requiring additional study within Theme III have been identified. The most significant of these can be summarised as:

- ❖ Developing optimal assimilation methods for diverse SST data products.
- ❖ Determining optimal pro cedures for relating and merging measurements of the different SST quantities (SST_{skin}, $SST_{sub-skin}$, and SST_{depth}) by different sensors.
- ❖ Ensuring accurate and consistent retrieval of SST from different sensors.

The first area concerning assimilation techn iques is directly linked to theme IV. Two topics in particular present new challenges for data assimilation. The first concerns the assimilation of multiple data sets with diverse error characteristics. Error statistics may vary between sensors but for many sensors, the error characteristics will also be related to coincident environmental conditions such as cloud content, water vapour, and wind speed. Methods to optimally treat multiple error statistics will require further development. The second topi c is the assimilation of SST measurements at different depths where it remains unclear as to how models should be modified to accurately incorporate data at different depths or if data should first be converted to a standard reference depth which is expected to evolve throughout the lifetime of the GHRSST-PP.

The second area focuses on relating the different measurement characteristics of each data source and can be described by three specific module activities.

Module III-I: Reconciling measurements at different depths.

The estimation of a standard SST_{depth} from satellite measurements was previously identified as a challenge for the GHRSST-PP. Reconciling the measurements at different depths provided by the various sensors will require accurately accounti ng for both warm layer and cool skin effects. During periods of strong insolation and light wind speeds, diurnal stratification results in complex relationships between SST_{depth} and $SST_{sub-skin}$ and temperature differences that can exceed a degree in magnitude. A SST_{depth} data product should properly account for vertical variability in the water column as discussed in § 1.2.1. In situ observations are insufficient for this purpose due to poor spatial coverage and calibration (e.g., Emery et al., 2001). In addition, uncertainties related to the many different types of sensor and deployment depths complicate collective analysis. At the cost of significant data rejection and a requirement for additional contemporaneous wind speed information, an estimate of SST_{1m} can be derived using both IR and PM satellite data streams filtered to include only those data at wind speed > 6 ms^{-1} when the upper ocean layer is expected to have a uniform temperature. Nevertheless, the low wind speed regime remains a significant problem: at lower wind speeds a cooler SST_{skin} prevails at night and stratification of the upper ocean layers may occur during the daytime causing significant vertical variations of SST (Ward and Minnett, 2001). The vertical structure of the upper 10 m of the water column in these conditions can only be obtained routinely, on the scales and resolution of the SST_{skin} retrievals, using accurate models of diurnal stratification and the thermal skin effect. These can be used to adjust low wind speed SST_{skin} or $SST_{sub-skin}$ satellite measurements to provide an SST_{1m} measurement. Further research, focussed on refining operationally applicable parameterisations and models of the skin–effect, diurnal stratification and the vertical variations of SST, is vital in ord er that SST_{skin} and/or $SST_{sub-skin}$ observations are reliably and accurately related to the SST_{1m} field.

Further evaluation and refinement of models for the near surface temperature profile and its evolution in the presence of diurnal warming are require d to ensure that the relevant physical processes are adequately understood and the temperature variations accurately reproduced. While temperature differences across the skin layer are smaller and appear to be well characterized by a near -constant bias at higher wind speeds, the differences are significant given the desired SST accuracy and may also be subject to significant variations at lower wind speeds. Further research into parameterisations of the skin effect is also vital to accurately relate diffe rent SST measurements.

Module III-ii: Reconciling measurements at different times.

Accounting for the effects and evolution of diurnal warming is also necessary for relating SST measurements collected at different times during the day. Use of data from mu ltiple sensors with different orbital geometry implies the existence of different measurement times.   This module in concerned with the validity of merging non -contemporaneous data sets to provide 6 hourly SST data products. If a common reference time is selected for an SST product and measurements are collected at multiple times or a time different from the reference time, the possible impact of diurnal temperature changes must be considered. The models for the evolution of the near   -surface temperature profile will also provide an estimate of the importance of these variations.

Module III-iii: Reconciling measurements at different spatial resolution.

Differences in spatial scale of the measurements are most important when comparing "point" in situ measurements with area averaged satellite measurements. Significant resolution differences also exist between the satellite products, however. If in situ and satellite measurements are to be used simultaneously in an analysis, the relative weighting and an ass   essment of how representative data are of a given context must be addressed.   This module is concerned with providing robust methodologies to merge satellite data obtained at different spatial resolutions.

Module III -iv: Ensuring accurate and consistent ret   rieval of SST from different sensors.

The final theme III module   incorporates issues related to radiative transfer and cloud detection methods used to produce the different satellite SST products. While some of the common satellite products are derived th rough the application of radiative transfer models, others have relied on regressions against in situ buoy data. It is not at all clear if individual products are to be incorporated using appropriate error characteristics or can improved results be obtain   ed through using a common radiative transfer based framework over all platforms?

A variety of different cloud detection techniques are also used in the different infrared product processing schemes and they represent one of the most critical steps in the   retrieval process. Potential areas of further research include integrating information from multiple sensors and platforms into the cloud detection within individual products, ensuring consistent approaches between the products, and developing confidence estimates in the cloud detection procedures that can be applied to the error characteristics of the products. Finally, investigations into the effects of cloud cover on retrieved satellite SST are required to establish if there are biases associated with satellite measurements only obtained in cloud free areas.

Additional issues for further research and development include:

- ❖ Exploration of the potential for future radiance-based assimilation techniques,
- ❖ Development of a robust system for the access and exc   hange of data from the multiple sources involved.

These areas will continue to be refined and through the interaction between the different thematic areas and the science team, priorities for the specific research activities will be established.

Efforts will be made to more fully coordinate and integrate existing relevant research activities. Work on several of the areas identified above is currently underway in different nations under different sources of funding. By providing a formal framework linking this research, the GHRRSST-PP will work to ensure that the results are efficiently shared and directly applied to the project activities. Where problems lacking adequate current research are identified, the GHRSST -PP will strive to promote appropriate new research initiatives.

2.5 Theme IV: Generation of improved, multi-sensor, SST products through integration and assimilation

There are many different SST data sets and data streams that will be considered by the GHRSST-PP: some of these are maintained operationally and others are undergoing development and testing. Techniques for assembling and integrating SST data sets maintained in a wide variety of different formats and held at many different locations are far from optimum. The aim of this theme is to fulfil strategic objective 3 and lies at the core of the GHRSST-PP. In practice the objective is to homogenize as much as possible the SST product def inition and content through exchange of information and expertise between producers. The following practical objectives are identified:

    4.1   Identify the data format (including compression formats), quality and sampling requirements for SST products derived from a representative sample of users drawn from all application sectors,

    4.2   Develop standards-based, metadata, data interoperability principles guidelines and priorities for GHRSST-PP and associated databases.

    4.3   To promote and assist the implementa tion of validated GHRSST -PP methods and techniques into existing operational SST processing systems.

Priority is given to the production of data according to the GODAE specifications. Homogenization of available SST data in terms of data definition and produc t content will be necessary building on the SDI tools and algorithms developed in theme III . The delivery delays should be consistent and SST products should be freely available through both the DDD and via ftp sites. Common formats may be desirable and in particular, netCDF, HDF, GRIB, BUFR..

Data from various sources (including conventional measurements) will be merged to provide the users with SST data as complete (i.e. without cloudiness induced gaps in IR data) as possible, or totally complete, while respecting the quality characteristics requested by the users. Demonstration SST data products will preserve as much SST structure and patterns as possible. Various product levels may be identified throughout the data production process . At each level th e product definition includes the physical definition of the parameter (see section 1.2.1) and the auxiliary information that together with the SST value defines the product content.
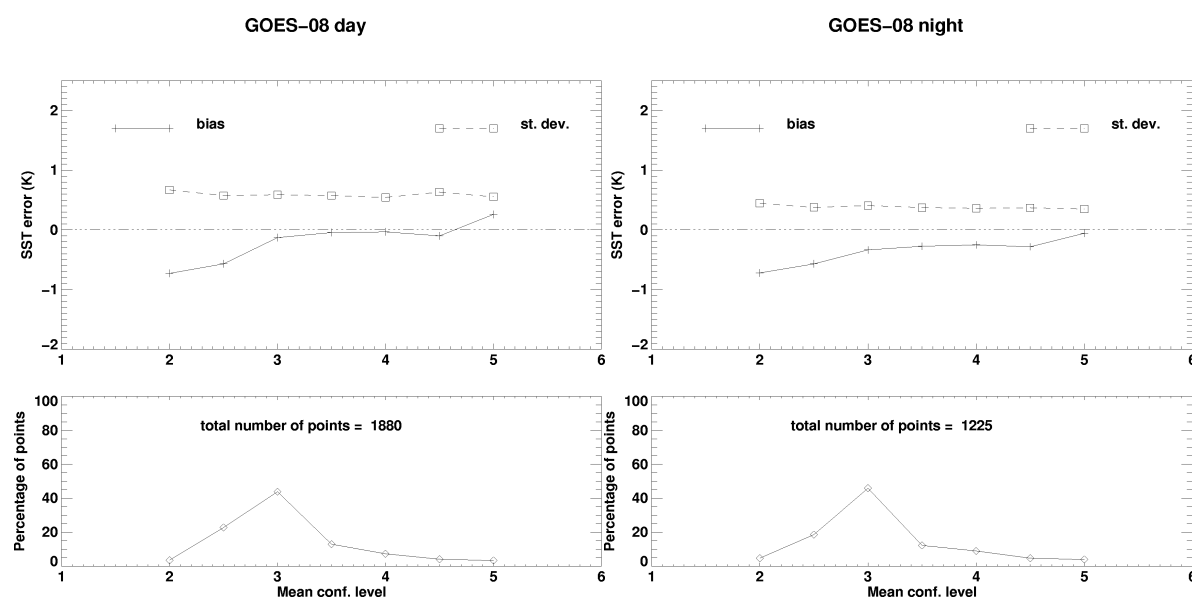

Figure 2.5.1 O&SI SAF GOES-08 validation statistics and relative number of points from 20 Aug. till 8 Sept 2001 as a function of the mean confidence level in the validation box, binned in 0.5 intervals. Confidence

levels have been defined from 2 ("bad") to 5 ("excellent") to reflect the possibility of contamination by cloudiness (from Brisson et al. 2001).

The standard product levels described here below as examples, and some of the related problems that have to be considered are briefly reviewed.

GHRSST-Level 2: mono satellite, single sensor, single orbit (or scene in the case of geostationary satellite) SST data: at this level data can be produced with their inherent definition: SST_{skin} from IR radiometer, $SST_{sub-skin}$ from PM. The auxiliary information include localization and time and should include a quality informa tion, ideally common to all products, at least well documented so that equivalences may be established from a product to another. This information is crucial for the further merging or OI analyses of the products. Figure 2.5.1 illustrates the sensitivity o f the IR derived SST errors as a function of the O&SI SAF confidence level.

GHRSST-Level 3: merged data (multi -orbits, multi -satellites, or multi -sensors): in this process inputs may have distinct definition and the merging rules and the output definition should be made clear. Similarly, outputs should have localization and time data and quality information should be provided.

GHRSST-Level 4: analyzed data. Buoy measurements are included in the fields, so that SST_{depth} (see section 1.2.1) is the most natu ral physical definition at this level. The SST_{skin} or $SST_{sub-skin}$ conversion to SST_{depth} may necessitate the availability of side products such as wind and radiation fields.

In practice the first phase of this Theme is to define the data producers that will be "operational" in 2003-2005, either on a global or at a regional scale.

The second phase will focus on the homogenization of methods and the definition of data products. If common definitions cannot be adopted due to time constraint, equivalences may be defined or recommendations issued.

3. Initial implementation plan for the GHRSST-PP

The GHRSST -PP has been established to provide international focus and coordination fo r the development of a new generation of global, multi -sensor, high -resolution, SST products. It provides an international consensus on what is required to provide a new generation of satellite SST data products. In this decade (2003 -2013), enhanced ocean data sampling from satellites (e.g., ENVISAT, EOS , ADEOS, MSG) and in situ (e.g., Argo and new operational SST_{skin} SOO campaigns) is expected and the GHRSST-PP aims to capitalise on these data to demonstrate the benefits and utility of global ocean SST products. Ocean sampling of this nature is not guaranteed for the future and the onus is on the user community to demonstrate that the benefits of the GHRSST-PP are tangible, valuable, and worthy of sustained support (GODAE, 2000) . This is important becaus e u nlike a national or international research program, there is no dedicated funding for GODAE or the GHRSST -PP. This must be considered as one of the critical items in designing an implementation plan. Following a period of preparation, during the 2003 -2005 GODAE demonstration phase, the GHRSST -PP should clearly demonstrate the operational advantages and value of including global data sets in climate and ocean modelling by the delivery of a demonstration data set.

The GHRSST-PP implementation plan aims to capitalise on existing activities by fostering national collaboration in data exchange, operational and scientific research and applications in order to minimise duplication of effort. Wide participation within the GHRSST-PP is encouraged and is open to all relevant activities. The GHRSST-PP implementation planning should be considered as an evolutionary process that is designed to conduct a two-year pilot project. It can be sub-divided into two sections each having a number of priority topics:

- ❖ A preparation phase
    - ▪ Targeted research
    - ▪ Implementation of basic GHRSST-PP networks
    - ▪ Data exchange infrastructure

- ❖ A demonstration phase
    - ▪ Product production
    - ▪ Product delivery
    - ▪ Product validation
    - ▪ Project validation

Table 3.1.1 shows a general implementation schedu le for the GHRSST -PP identifying the priority topics within the project.

	2002				2003				2004				2005			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Preparation Phase	▓	▓	▓	▓												
Implementation of DDD (DODS&FTP)	█	█	█	█												
Implementation of DDS	▓	▓														
Implementation of basic UIS	█															
Population of DDD and DDS	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
Testing of data delivery & exchange	▣	▣	▣	▣	▣	▣										
Version 1.0 SDI tools and methods	▤	▤	▤	▤												
Development of RT & OfL SST Algorithms (R&D)	▣	▣	▣	▣	▣	▣										
Demonstration Phase					▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
Extension of UIS system		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Continued development of v1.0 SDI					▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
RT & OfL SST Product generation		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
GHRSST-PP product validation		▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
Validation of GHRSST-PP									▨	▨	▨	▨	▨	▨	▨	▨
Delivery of GHRSST-PP products					▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒

Table 3.1.1. General implementation schedule for the GHRSST-PP

Within this perspective there are a number of relevant research projects and programs, both ongoing and planned, that have a significant role in determining the degree to which the GHRSST-PP will be successful which are discussed in Section 3.3.

3.1 GHRSST-PP preparation phase

The coordination and implementation preparations for the two   -year enhanced observing period commenced at the first GHRSST-PP workshop at the end of 2000. Intensive prepa rations for the demonstration phase of the GHRSST -PP will continue throughout 2002 cumulating in a "version 1.0" of GHRSST   -PP products and ser   vices that will be continually refined throughout the demonstration phase which continues until the end of the demonstration period (end of 2005). The following priorities are considered critical to the   successful planning and implementation of the GHRSST-PP.

Implementation of the GHRSST-PP dynamic distributed database (DDD).

The success of the GHRSST -PP will depend on scientists and agencies sharing their data with each other and requires an early and continuing commitment to the establishment, maintenance, validation, description, accessibility, and distributio n of data sets. The timely availability of source data is particularly important in this context.   Theme I provide the basis for developing a data

exchange and management system for the GHRSST-PP and making the data readily accessible to the scientific comm unity using the DODS architecture (i.e., multi -point and low cost access to relevant data, regardless of its location) and traditional network communication protocol (ftp). However, it is also foreseen that data may have to be exchanged in both an on -line and off -line modes. The DDD system will be a flexible but evolving data exchange and delivery system. The chosen framework is capable of accommodating modifications to data at source (assuring the most current versions of all data are available to users a nd facilitating the management of data sets) as well as the changes in data requirements over the duration of the project. But in order to function effectively, the distributed GHRSST -PP data system must act as a coordinated entity which requires the development of a comprehensive and accessible master metadata index. This should provide the location and a basic description of the content of data used within the project and could be linked to the Global Change Master Directory or other existing DODS infor mation data catalogue systems.

The DDD should be implemented in a "version 1.0" form by the end of 2002 and preferably, be in an advanced functional form within the first quarter of 2002.

Implementation of the GHRSST-PP diagnostic data set (DDS).

The DDS concept provides a manageable suite of globally distributed data that will be used to derive and test satell ite merging strategies, SST algorithm development and validation of source data and derived data products. It is foreseen that the DDS will be used extensively within the GHRSST-PP by many groups for these purposes and is arguably, together with the DDD, the core component of GHRSST -PP Themes III and IV. The DDS should be implemented within the framework of the DDD system. Theme II describes the basis for the structure and content of the DDS system which should be implemented in a functional form at the end of the second quarter of 2002.

Implementation of the GHRSST-PP user information service (UIS).

The UIS facility, which is in its most basic form a suite of WWW pages and a moderated on line discussion e -mail list, should be implemented at the start of 2002 in order to foster regular and active discussions as well as providing publicity and information of the GHRSST-PP. These pages should act as a focal point (portal) for the GHRSST -PP detailing aims objectives and the current status of the project. In additi on, the DDD master index should be accessible from this site as part of theme II activities.

Population of DDD and DDS

Population of the DDD and DDS should commence as soon as possible during the GHRSST -PP preparation phase. Data will be required by Theme III and Theme IV projects in order to prepare for the demonstration phase of the project.

Testing of data delivery & exchange

This priority activity includes the configuration of "push" and "pull" data feeds to operationa l agencies and other activities within the GHRSST -PP. These should be configured and tested before the demonstration phase of the project.

Development of RT & OfL algorithms

The objective of these activities is to address the science questions identified for data merging, product algorithms, product validation and cloud clearing strategies and specify suitable algorithms for implementation by the SDI. Many of these activitie s are currently active in national projects (e.g., merging of IR and PM data, clou d clearing strategies based on the use of time series data and combinations of IR and PM data sets). A tested version 1.0 suite of algorithms should be available by the start of the GHRSST -PP demonstration phase. More advanced algorithms will be developed, tested and implemented throughout the lifetime of the GHRSST-PP.

Version 1.0 SDI tools and methods

The target is to provide demonstration methodologies that will be used during the demonstration phase to generate the GHRSST -PP products. Initial activities will focus on the development of a suitable suite of software tools to implement the v.1.0 algorithms specified by the GHRSST -PP. It is expected that these tools will make use of the currently available data sets compiled by various agencies (ATSR, TMI, Pathfider etc.) within the DDD and DDS . A tested version 1.0 SDI toolkit should be available at the start of the GHRSST-PP demonstration phase. More advanced algorithms will be developed, tested and implemented throughout the lifetime of the GHRSST-PP.

3.2 GHRSST-PP demonstration phase

During the demonstration phase of the GHRSST -PP, the objective is to provide RT and OfL SST data sets according to the strategy outlined in the thematic work program . Throughout the demonstration phase, a parallel and continual process of project development and refinement is foreseen with particular emphasis on the improvement of demonstration data products and delivery to operational users. This will be achieved by maintaining careful and comprehensive validation of both GHRSST -PP products , using in situ and satellite observations and, a validation of the GHRSST-PP itself in terms of attaining the overall objectives of the project. The fo llowing priority activities have been identified.

Extension of UIS system

The UIS system should be maintained and where appropriate, extended to cover all aspects of the GHRSST-PP. Particular attention should be paid to ensuring that the UIS is a function al and useful resource for all parties associated with the GHRSST -PP rather than becoming a bloated set of marginal web pages. This requires careful thought and liaison with users and data producers.

Continued development of v1.0 SDI

It is unrealistic to expect that the SDI will be fully implemented at the start of the demonstration phase of the project as there are particularly demanding scientific and methodological questions to address. Therefore, it is expected that the SDI will continue to evolve ov er the course of the GHRSST-PP drawing on input from users and all scientific activities irrespective of those within the GHRSST-PP itself. In particular, the use of the DDS as a means to eva luate the SDI methodology will be a major component of this activity.

RT & OfL SST Product generation

The major distinction between the preparation phase and the demonstration phase o f the GHRSST-PP is the generation and delivery of data products during the demonstration phase of the GHRSST-PP. These activities are expected to evolve rapidly during the initial part of 2002 so that a stable system is established. However, it is also expected that this will be in a constant state of change as new users request different products as more experience is accumulated throughout the project.

Delivery of GHRSST-PP products

A closely related but nevertheless, independent activity, is the continued evolution of the GHRSST-PP data delivery and exchange system. In effect this requires the input of data users and will entail the tuning of the GHRSST-PP DDD to the particular needs of users (e.g., push and pull data streams in a particular format). This will be an evolutionary process as both users and the GHRSST-PP establish optimal data exchange protocols and systems.

GHRSST-PP product validation

The objective of this pri ority activity is to provide a quant itive validation of the GHRSST -PP demonstration data products using both in situ and satellite data. Validatio n is expected to assess the accuracy of demonstration data products, the validity of data merging strategies, cloud clearing methodology and the timeliness of data provision . It should result in clear statements at regular

intervals specifying the spatial and temporal resolution and accuracy Improvements to SST data . The basis for much of this work is described in Theme II and III of the GHRSST-PP strategy and focuses on the analysis of data within DDS system. T he results of this exercise are expected to feedback into all other activities of the GHRSST-PP.

Evaluation of the GHRSST-PP

This priority activity will critically review the GHRSST -PP in order to assess how well the proje ct is actually achieving its aims and objectives. This activity is started early on in the demonstration phase in order to have the possibili ty of addressing rapidly emerging problems early in the project. It will in particular, assess the usefulness of GHRSST -PP products by reviewing the successful application of these in the operational and scientific community as a whole . This will provide a validation of "user satisfaction" based on data delivery, product application, user comments and suggestions. It will also focus on obtaining a measure of the improved prediction skills achieved by operational models using GHRSST-PP data.

3.3 Currently active projects and activities

The following list describes current activities and identified projects relevant to the GHRSST-PP:

Activity	Contact	Status
Development and implementation of the GHRSST -PP diagnostic Data Set	EC-JRC, (C Donlon)	Active
Provision of MCSST and AVHRR brightness temperature data.	D. May, NAVOCEANO	In prep
Provision of TRMM TMI data products to the DDD and DDS	Remote Sensing Systems, (C. Gentemann)	Active
Eumetsat Ocean and Sea Ice (OSI) Satellite Application Facility (SAF) activities	P. LeBorgne, MeteoFrance	In prep
Access and use of ISCCP IR global brightness temperature data sets.	ISCCP, (B. Rossow)	In prep
Contribution to DDS sites, development of new products	NASDA (H. Kawamura)	In prep
Support to the development of the GHRSST-PP DDS	NASDA (I. Asanuma)	In prep
Provision of TRMM, AMSR/ADEOS-II, AMSR -E/AQUA SST and GLI/ADEOS-II SST	NASDA (H. Kawamura)	In prep
SDI merging tools and SST products for the global oceans and the western North Pacific	Tohoku University and NASDA (H. Kawamura)	In prep
Support and collaboration for DDS activities	SIMBIOS (J. Campbell)	Active
SSTskin SOO validation in European waters (ISAR project part of ENVISAT AATSR)	SOC (I. Robinson)	Active
THIRST proposal (part of Theme I module I-i)	SOC (I. Robinson)	In prep
SSTskin SOO validation in the Caribbean (M-AERI, part of MOIDIS validation)	RSMAS (P. Minnett)	Active
Provision of MODIS SST data sets	RSMAS (R. Evans)	In prep
Miami Pathfinder match up database	RSMAS (G. Podesta)	Active
Provision of ATSR ASST global data sets	RAL (C. Mutlow)	Active
Provision of Pathfinder ST data	JPL,PODAAC (J. Vazquez)	Active
SSTskin SOO validation activities (Pacific)	APL (A. Jessup)	In prep
R&D studies for merging IR & PM data	RSS, (C. Gentemann)	Active
R&D studies for merging IR and PM data	NOAA (G. Wick)	Active
R&D studies for merging IR and PM data	JRC (C. Donlon)	Active
R&D studies for merging satellite data	Meteo France SAF P. LeBorgne	Active
Provision of AVHRSS MCSST data	Navocean (D. May)	Active
Use of GHRSST-PP in operational models	UK Met. Office (N Rayner)	In prep
SST validation in Australian waters	CSIRO (Barton)	Active
R&D for satellite data analysis techniques	CSIRO(Barton)	Active
MODIS match-up database	RSMAS (Evans et al)	In prep

Table 3.3.1 Activities and projects within the GHRSST-PP (2000-2005)

4. Expected outcomes of the GHRSST-PP

GHRSST-PP demonstration data products are relevant to a large range of fields including regional issues such as weather forecasting, water quality, fisheries management, harmful algal blooms, and to global issues such as the ocean's role in climate change and the global carbon cycle. Significant national funding has been committed to the development and operation of new satellite platforms and senso rs (e.g., AATSR, AMSR, SEVIRI, MODIS, GLI, TMI) in order to preserve the long-term monitoring of the global ocean. The GHRSST -PP will ensure that data derived from existing and future sensors are used to their fullest extent, guaranteeing maximum return on investment. The proposed objectives, thematic work program and deliverables of the GHRSST-PP are focused on these priorities. Key outcomes of the GHRSST-PP include the following:

- The fundamental GHRSST-PP concept is that of deriving synergy from mergin g a number of existing satellite and in situ products from different sensors in a scientifically informed manner. In this way, it will improve the exploitation of Earth observation data sets by improving the quality and usefulness of space -based sea surfac e temperatures, for applications in operational ocean monitoring and forecasting for marine industries, for the establishment of climate baselines and detection of climate change, and for oceanographic science applications.
- The DDS concept will provide va luable near-real time feedback to data providers through the Diagnostic Data Set concept. In particular, calibration or data anomalies may be reported promptly facilitating rapid response actions.
- The GHRSST-PP will demonstrate an operational system with the involvement of many actors from data providing agencies to end users throughout the project life cycle. Ideally, it will ensure that the highest quality data sets are generated in an operationally efficient manner, (e.g., through the use of the dynami c distributed database approach) encouraging a sustained capability in operational services for monitoring SST from space. The GHRSST-PP will ultimately provide the tools, methods and research required to implement an operational system for the production of a new generation of global SST.
- Considerable scientific and operational knowledge will be gained during the lifecycle of the GHRSST-PP. This knowledge may be exploited in other projects within GODAE and in the wider international community. In particul ar, the project will foster better exploitation of existing data and adaptation of existing observing systems through the co -ordination of data integration methods, strategies and frameworks. These are required to fully capitalize on the complementary aspe cts of in situ observations together with satellite infrared and microwave satellite data sets.
- GHRSST-PP demonstration products address the global requirement (recently expressed by the operational NWP, oceanography and ocean science communities) for a st able high quality record of SST for climate change research, the demand for reliable monitoring of sea surface temperature as a climate indicator in its own right and as input to other climate indicators (e.g., through its fundamental influence on air-sea interaction).
- The GHRSST -PP will bring together many major international and national projects of differing scope and budget. It will ensure that scientists, data producers, and remote sensing specialists concerned with SST data at a global level are par ticipating in earth observation innovation, policy, decision-making and strategy formulation. It will also ensure that duplication of activities is minimized and synergy benefits of collaborative activities are maximized through synchronization of procedures, techniques, algorithms and data formats associated with the use and development of a long term, multi -sensor satellite SST data set.

5. Schedule for the GHRSST-PP

Release of this document November 1st 2001

Project preparation phase: 2001 -2002 (Implementation of DDS, DDD establish data exchange agreements and basic data merging strategies)
Project demonstration phase: 2002-2005 (delivery and refinement of GHRSST-PP products)

6. Final assessment of the GHRSST-PP

The co-ordination and synchronisation of international activities related to t he synergistic use of satellite data is fundamental to global environmental monitoring. The success of the GHRSST-PP will be judged primarily on the completeness of a new generation merged high -resolution SST maps that constitute the overall deliverable of the project. Their wide application, and in particular, the use of NRT high resolution data sets to the operational oceanographic and meteorological community data assimilation activities, will provide an unequivocal demonstration of the project success. However, before this can occur, it is clear that the GHRSST -PP, as an experiment, should lead to conclusions and recommendations that effectively guide the future developments of:

(i) New satellite missions concerned with the measurement of SST,
(ii) International coordination for the production of SST data sets,
(iii) Delivery and exchange of large data sets to the scientific and user community,
(iv) Targeted research and development of satellite derived SST,
(v) Validation and calibration of individual satellite sensors and data streams,
(vi) Requirements for a sustained operational global SST data service.

7. Contacts

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Annexe I: Acronyms

AATSR: Advanced Along Track Scanning Radiometer
AMSR: Advanced Microwave Scanning Radiometer
AOPC: Atmospheric Observation Panel for Climate
ATSR: Along Track Scanning Radiometer
AVHRR: Advanced Very High Resolution Radiometer
BUFR: Binary Universal Form for the Representation [of meteorological data]
CEOS: Committee for Earth Observing Satellites
CLIVAR: Climate Variability (program)
DCMI: Dublin Core Metadata Initiative
DDD: Distributed Dynamic Database
DIADEM: Development of Advanced Data Assimilation Systems for Operational Monitoring and Forecasting of the North Atlantic and Nordic Seas
ENSO: El nino Southern Oscillation
ESA: European Space Agency
GCOS: Global Climate Observing System
GHRSST-PP: GODAE High Resolution Sea Surface Temperature Pilot Project
GRIB: Gridded binary
GLI: Global Imager
GODAE: Global Ocean Data Assimilation Experiment
GOSSP: Global Observing System Space Panel
GTS: Global Telecommunications Service
IGOS: Integrated Global Observing Strategy
IGST: International GODAE Steering team
IPRC: International Pacific Research centre
IR: Infrared
ISO: International Standards Organisation
IOC: Intergovernmental Oceanographic Committee
JPL: Jet Propulsion Laboratory
METOP: Meteorological Operational polar satellites
MSG: Meteosat Second Generation
MODIS: Moderate Resolution Imaging Spectroradiometer
MW: Microwave
MTSAT: Multi-Functional Transport Satellite
MSMR: Multichannel Scanning Microwave Radiometer
Navocean: Navy oceanographic office
NWP: Numerical Weather Predication
NPP: NPOESS Preparatory Project
NPOESS: National Polar-orbiting Operational Environment Satellite System
OOPC: Ocean Observations Panel for Climate
OOSDP: Ocean Observing System Development Panel
PM: passive microwave
PIRATA: Pilot Research moored Array in the Tropical Atlantic
PODAAC: Physical Oceanography Distributed Data Archive
SAF: Satellite application facility
SDIE: Satellite Data Integration Engine
SEVIRI: Spinning Enhanced Visible and Infra-Red Imaging radiometer
SIMBIOS: Sensor Inter-comparison and Merger for Biological and Interdisciplinary Oceanic Studies
SOO: Ship of Opportunity
SST: Sea Surface Temperature
TAO: Tropical Atmosphere-Ocean
TMI: TRMM Microwave Radiometer
TOGA: Tropical Ocean Global Atmosphere (program)
TRMM: Tropical Rainfall Mapping Mission
VIIRS: Visible/Infrared Imager/Radiometer Suite
VOS: Volunteer Observing Ship
WCRP: World Climate Research Program
WMO: World Meteorological Organisation
WOCE: World Ocean Circulation Experiment
XBT: Expendable BathyThermograph

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